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SOURCE ASSESSMENT: GLASS CONTAINER MANUFACTURING PLANTS

by

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PREFACE

The Industrial Environmental Research Laboratory (IERL) of EPA has the responsibility for insuring that air pollution control technology is available for stationary sources. If control technology is unavailable, inadequate, uneconomical or socially unacceptable, then development of the needed control techniques is conducted by IERL. Approaches considered include: process modifications, feedstock modifications, add on control devices, and complete process substitution. The scale of control technology programs range from bench to full scale demonstration plants.

The Chemical Processes Section of IERL has the responsibility for developing control technology for a large number (> 500) of operations in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems.

Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL. This report contains the data necessary to make that decision for glass container manufacturing plants.

Battelle's Columbus Laboratories was contracted with EPA to investigate the environmental impact of the glass container industry, which represents a source of emissions in accordance with EPA's responsibility as outlined above. Dr. J. Richard Schorr served as Program Manager for this study. Mr. Edward J. Wooldridge served as EPA Project Monitor. The study was completed by IERL-RTP. Project responsibility was transferred to the Industrial Pollution Control Division of IERL-Cincinnati on October 15, 1975.

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16. ABSTRACT The report summarizes results of a study to gather and analyze background information and technical data related to air emissions from glass container manufacturing operations. It covers emissions from three plant areas: raw materials preparation and handling, glass melting, and forming and finishing operations. Melting furnace emissions account for over 95 percent of the total plant emissions. The major pollutants are NOx, SOx, and submicron particulates consisting mainly (over 90 percent) of mineral sulfates. NOx has the largest emission factor (3 g/kg) with annual emissions of 36.5 x 10 to the 9th power g. Compared with national emissions from stationary sources, NOx emissions from glass melting furnaces contribute 0.34 percent of the total. Source severity factors determined by this study were 0.38 for NOx, 0.56 for SOx, and 0.035 for particulates, with others being less than 0.01. Source severity is a measure of the potential environmental effect of air emissions and is the ratio of the maximum average ground level concentration to the primary ambient air quality standard for criteria pollutants.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Dust	Air Pollution Control	13B	11G
Assessments	Minerals	Source Assessment	14B	08G
Glass Industry	Sulfates	Stationary Sources	11B	
Containers		Particulate	13D	
Nitrogen Oxides		Mineral Sulfates	07B	
Sulfur Oxides				

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LIST OF SYMBOLS

Symbol	Definition
AAQS	Ambient air quality standard
A, B, C, D, E, F	Atmospheric stability classes
a, b, c, d, e, f	Constants in dispersion equations
A_R	The ratio $Q/ac\pi u$
B_R	The ratio $-H^2/2c^2$
CI	Confidence Interval
D_i	Inside stack diameter
e	Natural logarithm base
H	Effective stack height
h	Physical stack height
ΔH	Plume rise
k	"Student t" test variable
m	Number of samples
N_i	Sample value
p	Atmospheric pressure
Q	Mass emission rate
R	Downwind dispersion distance from source of emission release
s	Sample standard deviation
S	Source severity, ratio $\overline{X}_{max}$/AAQS
T_a	Ambient temperature
T_s	Stack gas temperature
t_o	Instantaneous averaging time of 3 minutes
t	Averaging time
TLV	Threshold limit value
u	National average wind speed
v_s	Stack gas exit velocity
R	Horizontal distance from centerline of dispersion

LIST OF SYMBOLS (Continued)

Symbol	Definition
μ	Sample mean
π	3.14
σ	Standard deviation
X	Downwind ground level concentration at reference coordinate x and y with emission height of H
$\bar{X}$	Time average ground level concentration of an emission
X_{max}	Instantaneous maximum ground level concentration
$\bar{X}_{max}$	Time average maximum ground level concentration

SECTION I

INTRODUCTION

Air emissions released in the manufacture of glass containers were examined in this study. This report describes the glass-container industry, the nature of air emissions and their environmental impact, the control technology employed, and the future growth of this industry.

Glass containers represents the largest of three segments of the glass industry (glass containers, flat glass, and pressed-and-blown glassware). Each segment is defined by a Standard Industrial Classification (SIC) number, as used by the Department of Commerce. Glass containers is designated by SIC 3221 and includes the manufacture of glass containers for food, beverages, medicines, toiletries, and cosmetics. This includes both narrow-neck and wide-mouth containers. Shipments in this segment have grown at an average rate of about 3.5 percent since 1971. Industry shipments in 1973 had a value of $2.3 billion, or about 51 percent of the glass industry total.

Flat glass is designated by SIC 3211. This includes both the manufacture of flat glass and some fabrication of flat glass into a tempered- or laminated-glass product. Flat-glass products include: window glass, plate glass, wire glass, tempered glass, and laminated glass. These products are consumed primarily by the automotive and construction industries. Value of shipments in 1973 was $1.1 billion, which was 24 percent of the whole glass industry.

Pressed-and-blown glassware is designated by SIC 3229 and includes all glassware not classified under SIC 3221 or SIC 3211. This industry segment is very diversified and includes products such as:

- Table, kitchen, art, and novelty glassware
- Lighting and electronic glassware
- Scientific, technical, and other glassware
- Textile fibers.

Industry shipments in 1973 had a value of $1.3 billion, which was about 25 percent of the total industry.

Table 1 gives some 1973 statistics on the three segments of the glass industry. It shows that over 154,000 people produced merchandise valued at over $4.5 billion. Some 70 percent of the glass products are made by the glass-container segment.

Separate Source Assessment Documents were prepared for the flat-glass and pressed-and-blown glassware segments. This report deals only with glass containers; however, some of the same emissions and control technology will also be found in the other glass industry segments. The report delineates the various emission points, identifies the type and quantity of emissions, and describes the characteristics of the air pollutants found. The mass emissions of criteria pollutants (particulates, NO_x, SO_x, and CO and hydrocarbons) from glass container plants are compared with national emissions from all stationary sources. The maximum average ground-level concentrations of emissions from a glass-container plant are compared to the corresponding ambient air-quality standards. Control technology which is being used or could be applicable to the manufacture of glass containers is also discussed.

The manufacturing operations for glass containers is grouped into three categories:

- Preparation of raw materials
- Glass melting
- Forming and finishing.

Emissions and control technology for each of these three areas is presented.

TABLE 1. GLASS-INDUSTRY STATISTICS[a]

SIC	Industry Segment	1973 Employees, (10^3)	1973 Value of Shipments, ($ Million)	1973 Shipments[b], (Metric Tons x 10^6)
3221	Glass Containers	77.8	2,316	11.32
3211	Flat Glass	26.3	1,118	3.12
3229	Pressed-and-Blown Glass[c]	50.0	1,120	1.57
	Total	154.1	4,554	16.01

(a) Source: Department of Commerce and References 1 and 15.
(b) Metric Ton = 10^{12} grams.
(c) Excludes textile fibers.

SECTION II

SUMMARY

This document describes a study of air emissions released during the production of glass containers. The industry is defined by Standard Industrial Classification (SIC) No. 3221. It encompasses the preparation of raw materials at the plant site, the production of molten glass in a furnace, the forming of glass containers, and certain post-forming operations required to manufacture these products.

The glass-container industry in the United States produced 11.005 Tg* (12.133 million ton) of salable product in 1974. Of that total, about 15 percent (1.651 Tg) was amber glass; the remainder (green and clear glass) is classified as flint glass. In 1974, the domestic glass-container industry consisted of 25 manufacturers operating 120 plants. Geographically, these plants are located near the local markets they serve, with the largest concentration being in the East, North-Central, and Middle Atlantic regions of the country. Glass-container plants are located in 29 states; California, Illinois, Indiana, Ohio, Pennsylvania, and New Jersey are states with the largest number of manufacturers. The average county population density at a plant site is estimated to be 356 people/km^2.

Manufacturing Technology

In a glass-manufacturing process, raw materials (e.g., sand, soda ash, limestone) are uniformly mixed and these loose materials transported to a furnace where they are melted at elevated temperatures (>1500 C) into a homogeneous mass. More than 95 percent of the glass is made in fossil fuel-fired furnaces where energy is predominately transferred to the glass by radiation from a flame or reradiation from the refractory chamber containing molten glass. Molten glass is kept at elevated temperatures until it is of a quality (bubble-free) sufficient for making containers.

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* Tg = 10^{12} gram. Metric prefixes and other conversion factors are given in Appendix F, Page F-1.

The glass is then cooled to approximately 1300 C, removed from the furnace, and cut into "gobs". The gobs are fed to a machine and formed into containers. Approximately 30 percent of these containers then undergo surface treatment and about 3 percent are decorated. The exact operations used in a specific plant depend upon the type of product desired. All containers go through a gas-fired annealing furnace for removal of residual stresses. Highest temperatures during annealing range from about 590 to 650 C.

Emissions

Emissions were examined from three areas within the glass-container manufacturing plant: (1) raw-materials preparation and handling, (2) glass melting, and (3) forming and finishing. The largest emissions occur from the glass-melting operation.

Manufacturing Plant

Table 2 summarizes the average emissions of major species from a glass-container manufacturing plant determined by this study. While emissions for amber and flint glass are discussed separately in the report, significant differences were not found, and the data in Table 2 is for a plant producing flint glass. The emissions listed are for an average plant production capacity of 319 Mg/day (352 ton/day). Annual production was 105 Gg (90 percent of capacity). This table shows that over 97 percent of the plant emissions come from the glass-melting furnace. The major species (over 90 percent) are NO_x, SO_x, and particulates. Furnace stack heights average 26 m (65 ft) when ejection air is used and 45 m (147 ft) for natural draft.

Total Industry

Nitrogen oxides have the highest emission factor (3.07 g/kg ± 47%). This includes both flint and amber glass as shown later in Table 8. Total annual emissions are 38.9 Gg. Accordingly, NO_x contributes the greatest amount to the national NO_x emissions from all stationary sources (0.34 percent).

TABLE 2. AVERAGE EMISSIONS OF MAJOR SPECIES FROM GLASS-CONTAINER PLANT[(a)]

	Emission Species						
	NO_x	SO_x	Particulates	CO	Hydrocarbon	Selenium	HCl
EMISSION FACTOR, g/kg[(d)]							
(1) Raw Materials	0	0	0.03 ± 100%	0	0		
(2) Glass Melting	3.40 ± 43%	1.84 ± 36%	0.71 ± 30%	0.06 ± 170%	0.08 ± 100%	0.002 ± 100%	
(3) Form and Finish	0.02 ± 100%	0	0.05 ± 100%	0.002 ± 100%	4.43 ± 100%		0.02 ± 100%
TOTAL ANNUAL EMISSIONS, Mg							
(1) Raw Materials	0	0	4	0	0		
(2) Glass Melting	358	193	86	6	8	0.2	
(3) Form and Finish	2	0	2[(b)]	0.2	10.8[(c)]		0.6[(b)]

(a) Production 319 Mg/day (352 ton/day), assuming 85 percent pack rate of flint glass or 104.8 Gg/yr.

(b) Represents primarily surface treatment emissions for 30 percent of production.[(2)]

(c) Represents decorating emissions for 3 percent of production (42%) and emissions from annealing lehrs (29%) and forming operations (29%).

(d) Emission factors are only for flint glass, which constitutes an estimated 85 percent of glass production. Emission factors for both flint and amber are given later in Table 8.

Sulfur oxides have the next highest emission factor which is 1.70 ± 47%. This includes both flint and amber as given in Table 8. Total annual emissions are 21.6 Gg. This amounts to 0.31 percent of the national emissions from all stationary sources.

Particulates for both flint and amber glass were determined to have an emission factor of 0.68 g/kg ± 36%, with total annual emissions of 8.6 Gg. This would be 0.007 percent of national emissions from all stationary sources.

Carbon monoxide has an emission factor of 0.07 g/kg ± 143% with total annual emissions of 0.9 Gg. The emission factor for hydrocarbons was 0.08 g/kg ± 100% with total annual emissions of 0.7 Gg. These contribute 0.005 and 0.003 percent respectively to the national emissions from all stationary sources. Finally, the emission factor for selenium was 2 mg ± 100% with total annual emissions of 0.02 Gg.

Emissions from raw-materials preparation and handling do give rise to some particulate emissions, primarily from dust generated during discharging, conveying, crushing, and mixing operations. Composition of the emissions is the same as that of the raw materials (i.e., sand, limestone, soda ash). The average emission factor is 0.03 g/kg ± 100%. Total annual emissions for the glass container industry were estimated to be only 459 Mg or 0.0003 percent of the national particulate emissions from all stationary sources. Over 90 percent of the industry employs controls (primarily filter bags) in dust generating areas.

Many different processes can be used in the forming and finishing operations. Emissions of the major species from forming and finishing are relatively low, as can be seen in Table 2. These emissions consist of hydrocarbons emitted from the forming operation (0.03 g/kg), tin oxide and hydrated tin chloride particulates and HCl emitted from a surface treatment operation performed on about 30 percent of the containers produced. Combustion products are emitted from gas-fired annealing and decorating lehrs, and hydrocarbons are emitted from decorating operations used with about 3 percent of the glass container production. The emissions from all of these areas have been combined in Table 2, because relatively speaking they constitute less than 2 percent of the emissions from a normal manufacturing plant. They are broken out by emission source and type in the body of the report.

Control Technology

Emissions from glass container melting furnaces are generally not controlled by add-on equipment. This is not the case in every State. Frequently emission standards can be met with proper operating conditions. Baghouses and electrostatic precipitators are used by a few manufacturers to control submicron particulate emissions.

Source Severity

Impacts of these emissions are directly related to the ambient concentrations the emissions create at ground level. Atmospheric dispersion calculations were made to calculate maximum average ground-level concentrations ($\bar{X}_{max}$) for the emissions from an average plant producing 105 Gg/year. Results of these calculations are presented in Table 3.

Source severity factor, S, has also been used to describe the impact of the emissions. For those pollutants which have an ambient air-quality standard (AAQS), S is the ratio of $\bar{X}_{max}$ to the primary AAQS. In cases where no AAQS has been established, S is based upon the Threshold Limit Value (TLV) through the following equation which includes a factor for correcting the TLV to a 24-hour day (8/24) and a safety factor (1/100).

$$S = \frac{\bar{X}_{max}}{TLV\ (8/24)\ (1/100)}$$

Results of the source severity factor calculations also appear in Table 3. The highest severity factor (0.38) is produced by nitrogen oxide emissions from the melting furnace and hydrocarbon emissions from decorating lehrs (0.15). Other severity factors were less than 0.05.

A third measure of the impact of the plant emissions is given by the affected population. This measure is defined as the population around the representative plant who are exposed to a source severity factor greater than 1.0. Computations of the affected population showed that all sources were less than 1.0. Nitrogen oxides would be the highest if computed on a more restrictive basis such as a source severity factor of 0.1. In this case 11,700 persons would be affected.

TABLE 3. SOURCE SEVERITY FOR GLASS-CONTAINER EMISSIONS(a)

Source-- Pollutant	Primary Ambient Air-Quality Standard $\mu g/m^3$	Averaging Time, hr	Maximum Average Ground-Level Concentration, $\bar{X}_{max}$ $\mu g/m^3$	Severity Factor
Melting Furnace--				
NO_x	100	24	37.9	0.38
SO_x	365	24	20.5	0.056
Particulates	260	24	9.2	0.035
CO	4×10^4	8	0.8	2×10^{-5}
Hydrocarbons	160	3	0.9	5.9×10^{-3}
Selenium	Trace(b)	24	Trace(b)	
Materials Handling--				
Particulates	260	24	0.02	9.2×10^{-5}
Container Decorating--				
Hydrocarbons	160	3	23	0.15
Surface Treatment - HCL	Trace(b)	24	Trace(b)	

(a) Other severity factors, including those for selenium, tin particulates, and HCl were quite low.

(b) Trace <10 $\mu g/m^3$.

Future Growth

Historically, the glass container industry's growth has fluctuated considerably in the past 8 years, but shipments have steadily increased since 1967 at an average annual rate of 6 percent. A large portion of this growth is attributable to the popularity of the nonreturnable beverage bottle. In more recent years, growth in shipments has been less. Future growth may well be tied to legislation restricting use of nonreturnable containers. It is likely that 1980 production levels will be 20 percent higher than for 1974. Emissions would increase proportionally and possibly at an increased rate, since the industry is moving away from the use of natural gas to the use of oil. The actual effect of conversion from gas to oil firing on emission rates is not known.

SECTION III

DESCRIPTION OF GLASS-CONTAINER INDUSTRY

This section describes in general terms the process steps used in the manufacture of glass containers and presents certain statistical information pertinent to the glass-container industry described by the Department of Commerce for Standard Industrial Classification (SIC) 3221.

General Process Description

Figure 1 is a process-flow diagram which generally depicts the flow of materials through a glass container manufacturing plant. The process is categorized into four steps: batch handling, melting and fining, forming, and postforming. These specific steps are discussed in more detail later in this section of the report.

Basically, the manufacture of glass containers consists of melting (and reacting) a mixture of raw materials (consisting primarily of silica, soda, and lime) which have been prepared in the batch-handling step so as to minimize segregation and impurities in the batch. Cullet (scrap glass) is also added at this stage. In the glass melter, the materials are melted down, the molten glass is fined (i.e., residual trapped gases are removed), and then the temperature of the glass is lowered so that it can be handled in the forming step. The glass passes from the melter to the forming equipment via the forehearth, a relatively shallow, narrow refractory channel having a refractory roof and individual heating and cooling systems for controlling glass temperature. Individual gobs of glass are fed to the forming machines where the molten glass is transformed into a product by one of two methods: blow and blow, or press and blow. The formed container may now go through a series of postforming steps, depending upon the product desired, but which always includes annealing, where stresses are removed through a controlled, uniform-cooling cycle. Finally, the containers may undergo various additional steps, such as surface treatment, inspection, testing, decoration, and plastic coating.

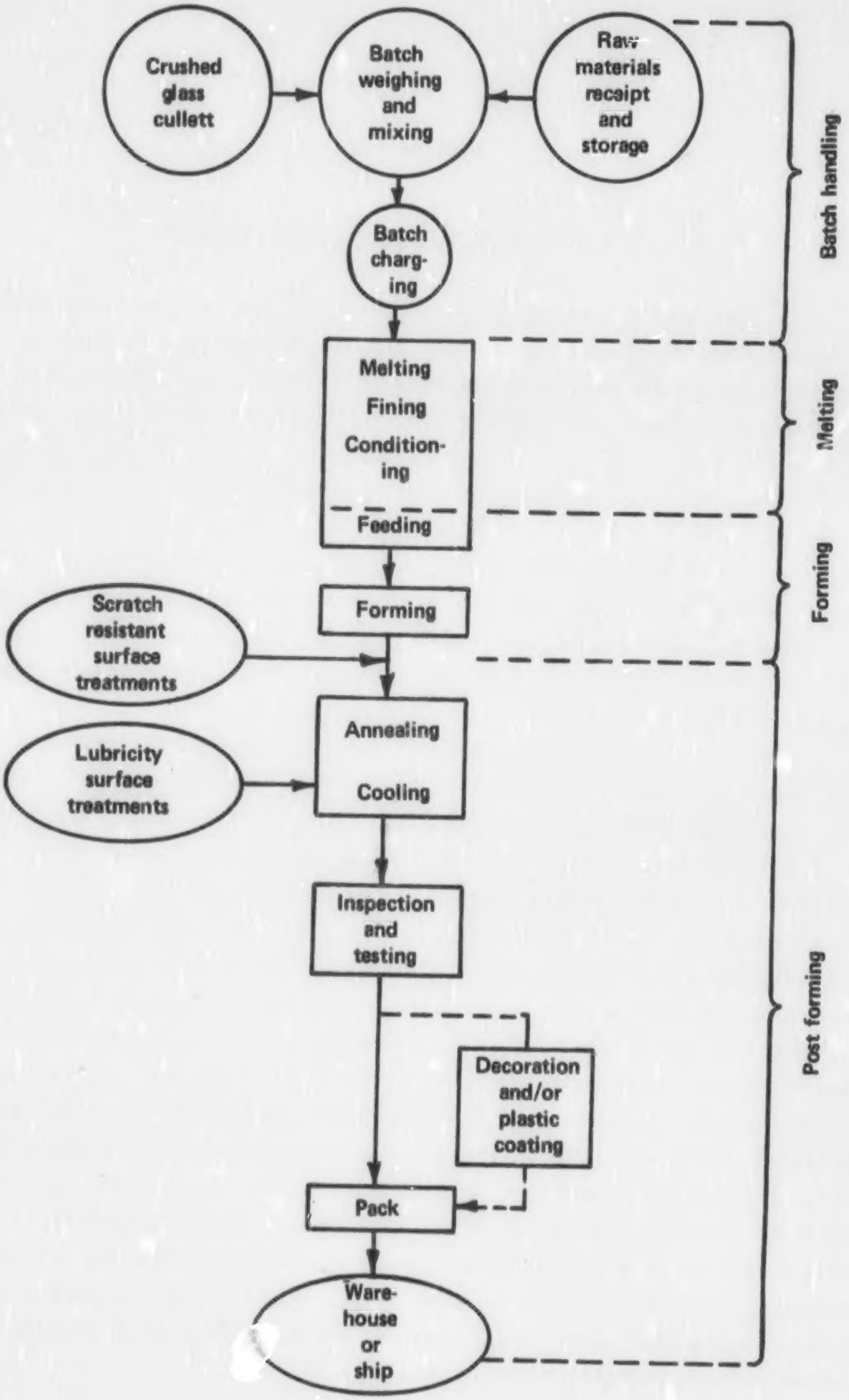
Crushed glass cullett
Batch weighing and mixing
Raw materials receipt and storage
Batch charging
Melting
Fining
Conditioning
Feeding
Forming
Scratch resistant surface treatments
Annealing
Cooling
Lubricity surface treatments
Inspection and testing
Decoration and/or plastic coating
Pack
Warehouse or ship
Batch handling
Melting
Forming
Post forming

FIGURE 1. PROCESS-FLOW DIAGRAM FOR GLASS CONTAINERS (SIC-3221)

Plants and Locations

According to information gathered from the Department of Commerce 1972 Census of Manufacturers(1)* and from the Glass Containers Manufacturers Institute (GCMI)(2), there were 120 establishments manufacturing glass containers in the United States. These 120 plants (see Appendix A) are operated by 25 manufacturers as shown by Table 4. Statistics obtained from 1975 glass-industry directories and from industry sources(2-5) indicate that approximately half of these plants are operated by the five largest companies.

Geographically, glass-container plants are located near the local markets they serve. As such, plants are found throughout the United States, but a large number are concentrated in the East North Central and Middle Atlantic portion of the United States. The states containing the largest number of manufacturers are California, Illinois, Indiana, Ohio, Pennsylvania, and New Jersey. The regional distribution of the major plants is shown in Figure 2.

Shipment Volume and Weight

Table 5 provides estimated 1974 output data for the glass-container industry (SIC 3221). The volume of shipments for 1974 was 276,382 thousand gross as compared to 267,732 thousand gross in 1972, or only 3.2 percent growth for the 2-year period. The weight of glass containers shipped increased from 10,772 Gg (23,748 million pounds) in 1972 to 11,005 Gg (24,266 million pounds) in 1974, or an increase of 2.1 percent. Three general types of container glass are produced: amber, green, and clear. For this report, green and clear glass are considered together as a single category designated as flint. The major difference between these two is the iron oxide additions. Emission data was not found to be separately reported. Figure 3 illustrates the estimated breakdown between amber and flint.

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* References are listed on page 86.

TABLE 4. MAJOR GLASS-CONTAINER MANUFACTURERS IN THE UNITED STATES(a)

Manufacturer	No. of Plants	Manufacturer	No. of Plants
Anchor Hocking	9	Latchford Glass	1
Arkansas Glass	1	Leone Industries	2
Ball Corporation	4	Liberty Glass	1
Bartlett Collins	1	Madera Glass Co.	1
Brockway Glass	14	Metro Glass	4
Chattanooga Glass	7	Midland Glass	4
Columbia Gas	1	National Bottle Corp.	4
Diamond Glass	1	National Can	4
Gallo Glass	1	Owens-Illinois	20
Glass Containers Corp.	12	Thatcher Glass	6
Glenshaw Glass	2	Underwood Glass	1
Hillsboro Glass	1	Wheaton Glass	2
Indian Head	7		
Industrial Glass	1	Total	120
Kerr Glass	7		

(a) Source: Material provided from GCMI, dated 10/24/75.

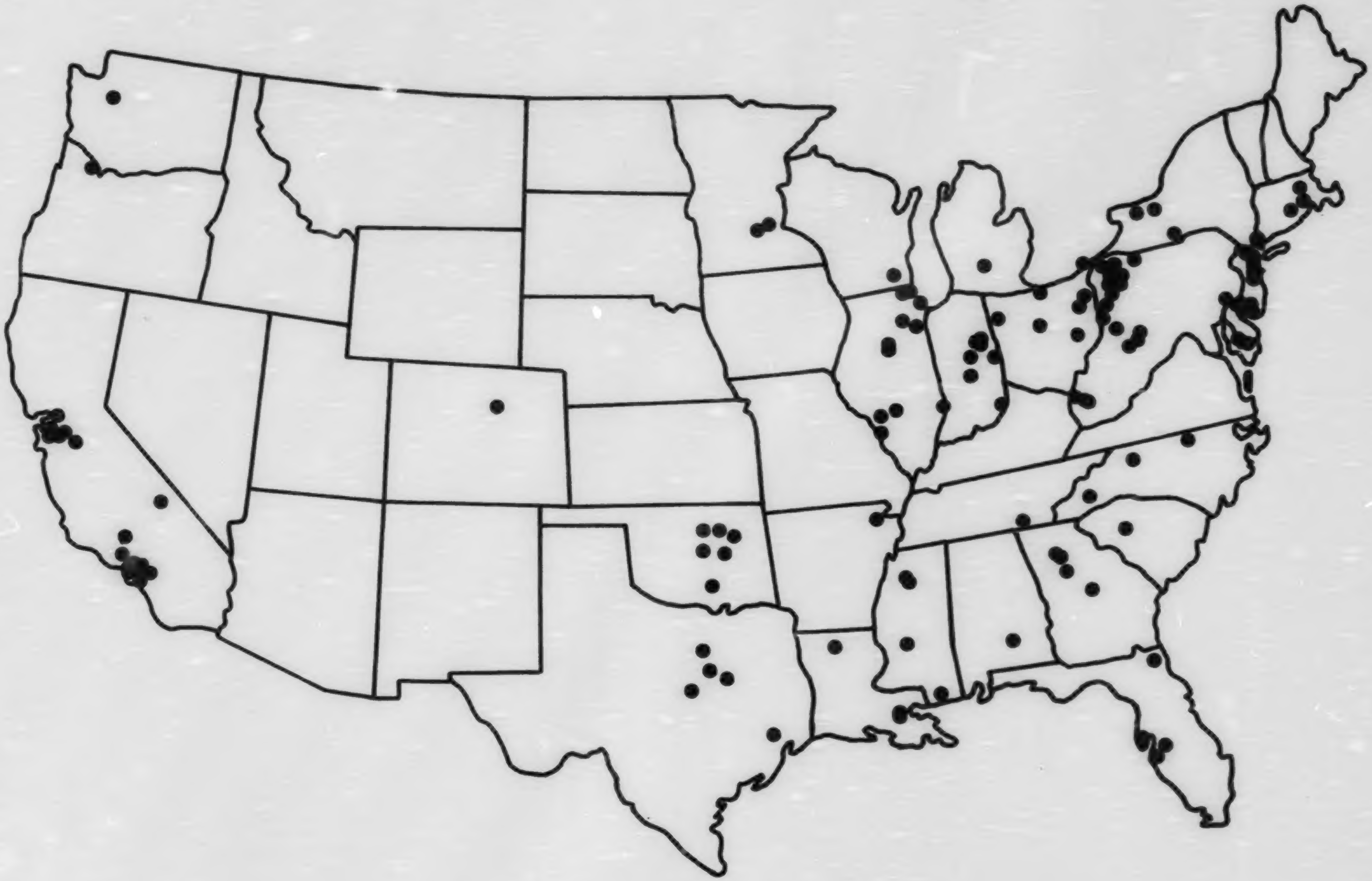

FIGURE 2. LOCATION OF GLASS-CONTAINER OPERATIONS$^{(6)}$

TABLE 5. PRODUCT SHIPMENTS OF THE GLASS-CONTAINER INDUSTRY
(Department of Commerce Classification SIC-3221)

Shipments of All Types of Glass Containers(a)					
1974		1973		1972	
Number(b)	Weight,Gg	Number(b)	Weight,Gg	Number(b)	Weight,Gg
276,382	11,000	276,328	11,326	267,732	10,748

(a) Sources: U.S. Department of Commerce, Bureau of the Census, Series M32G(74)-13 and Statistics Glass Containers 1975 published by *The Glass Container Manufacturers Institute*.

(b) Number of containers in thousands of gross.

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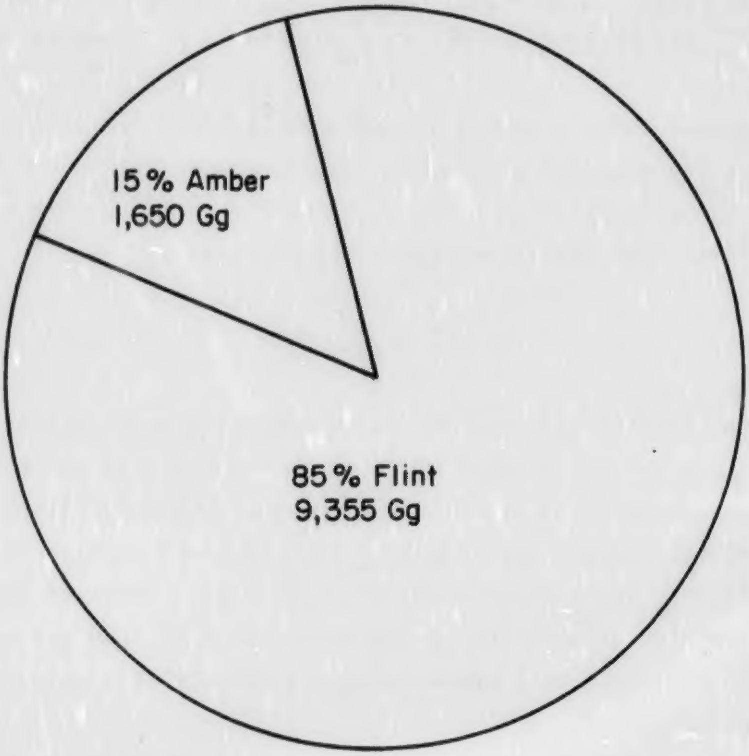

FIGURE 3. APPROXIMATE BREAKDOWN OF THE TYPES OF CONTAINER GLASS (1974)(15)

Process Details

While specific equipment will vary, depending upon the manufacturer and the product being made, the basic manufacturing process is essentially the same for all glass-container manufacturers. Portions of raw materials are mixed with each other and with cullet (scrap glass), conveyed to a melting furnace, melted, fined, conditioned, and fed into forming machines. The formed containers are then taken through a variety of postforming and product-handling steps.

The subsequent paragraphs describe the process operations and the raw material ingredients; thus indicating the potential sources of materials that can be emitted into the air as pollutants. Figure 4 schematically shows the overall manufacturing process.

Batch Handling

The function of the batch-handling operation is to prepare and feed to the melting furnace a batch which is both chemically and physically uniform in composition. Control of the composition, impurity level, and the size and moisture of the raw materials is important. Cullet is crushed and either mixed with the raw materials or added later. Each of the raw materials is carefully weighed, mixed together, and then conveyed to the batch chargers. Care must be taken so that segregation of a uniformly mixed batch does not occur.

A large plant manufacturing container glass usually houses the raw material mixing and conveying equipment in a structure termed a "batch house", A flow diagram of a typical batch house is shown in Figure 5. In most batch houses, the storage bins are located on top, with the weigh hoppers and mixers located below them to make use of gravity flow.

Major raw materials and cullet (broken scrap glass) are conveyed from railroad hopper cars or hopper trucks by a combination of screw conveyors, belt conveyors, and bucket elevators, or by pneumatic conveyors to the elevated storage bins. Minor ingredients are usually delivered to the plant in paper bags or cardboard drums and transferred by hand to small bins.

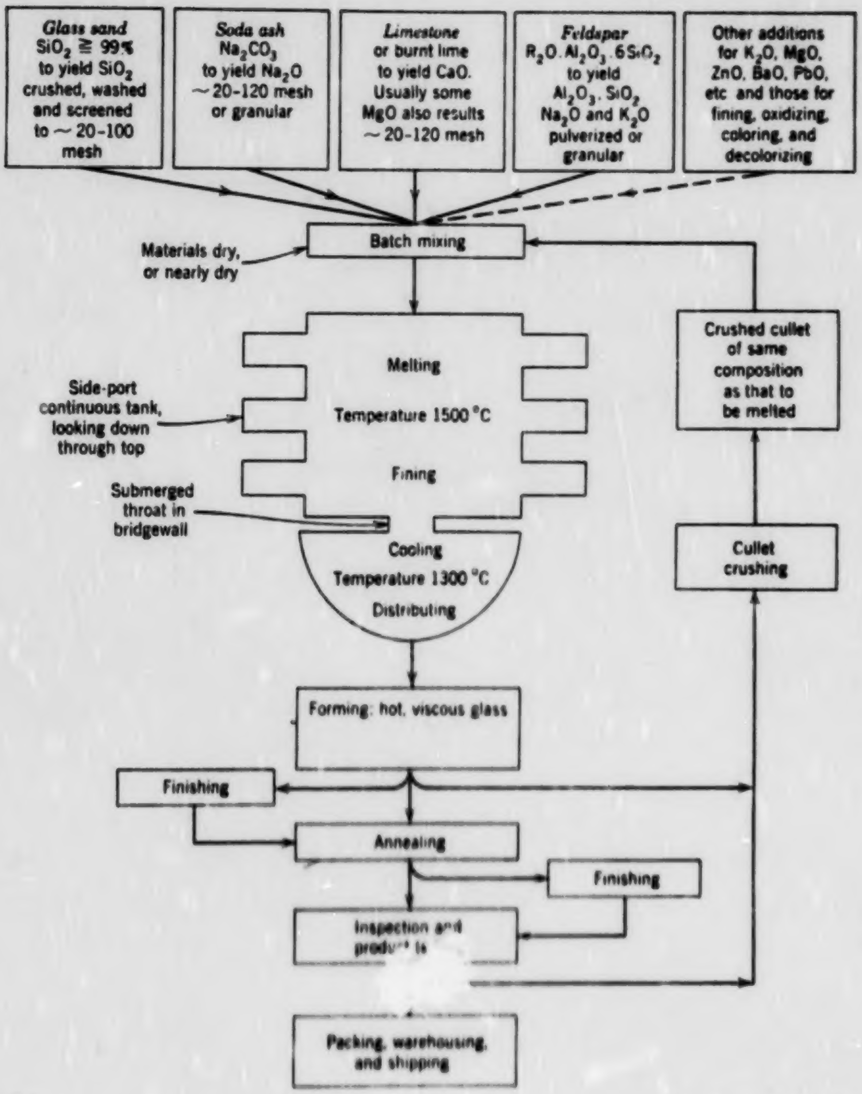
Glass sand
$SiO_2 \geqq 99\%$
to yield SiO_2
crushed, washed
and screened
to ~ 20-100
mesh
Soda ash
Na_2CO_3
to yield Na_2O
~ 20-120 mesh
or granular
Limestone
or burnt lime
to yield CaO.
Usually some
MgO also results
~ 20-120 mesh
Feldspar
$R_2O.Al_2O_3.6SiO_2$
to yield
Al_2O_3, SiO_2
Na_2O and K_2O
pulverized or
granular
Other additions
for K_2O, MgO,
ZnO, BaO, PbO,
etc and those for
fining, oxidizing,
coloring, and
decolorizing
Batch mixing
Materials dry,
or nearly dry
Melting
Temperature 1500 °C
Fining
Side-port
continuous tank,
looking down
through top
Submerged
throat in
bridgewall
Cooling
Temperature 1300 °C
Distributing
Crushed cullet
of same
composition
as that to
be melted
Cullet
crushing
Forming: hot, viscous glass
Finishing
Annealing
Finishing
Inspection and
product [illegible]
Packing, warehousing,
and shipping

FIGURE 4. GLASS-CONTAINER MANUFACTURE(7)

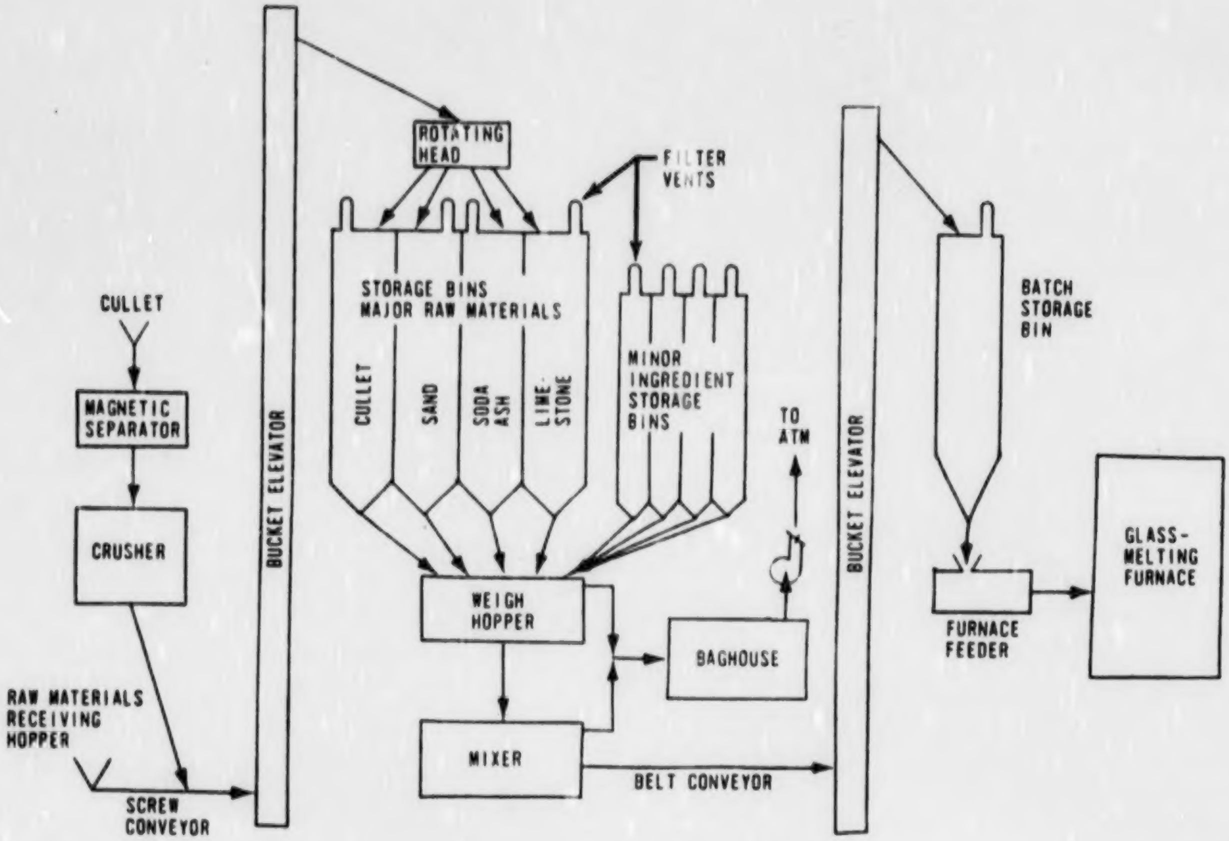
CULLET
MAGNETIC SEPARATOR
CRUSHER
RAW MATERIALS RECEIVING HOPPER
SCREW CONVEYOR
BUCKET ELEVATOR
ROTATING HEAD
FILTER VENTS
STORAGE BINS MAJOR RAW MATERIALS
CULLET
SAND
SODA ASH
LIME-STONE
MINOR INGREDIENT STORAGE BINS
WEIGH HOPPER
MIXER
BELT CONVEYOR
BAGHOUSE
TO ATM
BUCKET ELEVATOR
BATCH STORAGE BIN
FURNACE FEEDER
GLASS-MELTING FURNACE

FIGURE 5. PROCESS FLOW DIAGRAM OF A TYPICAL BATCH PLANT(9)

Materials are gravity fed from the storage bins into weigh hoppers and then transported by transverse belts or bucket elevators into a mixer. Cullet is crushed to a desired size (usually between 0.5 and 2.0 cm). After mixing, the glass batch is transferred to a charging bin located next to the glass-melting furnace or into a batch-storage bin, depending upon the design of the batch-handling system. Positive displacement or vibrator feeders at the bottom of the bins feed the materials to the glass-melting furnace chargers. Cullet may be added to the batch in the mixer, while the batch is being transferred, or charged separately to the melting furnace(8).

Batch is fed into the melter in either a dry or moist state. Many companies add two to four percent water to the dry batch to help prevent segregation during transport of the batch, to minimize dust problems in the melter, and to avoid carryover of dust into the regenerators.

The various handling and mixing operations are a source of particulate emissions which are similar (same materials, same processes) as those in other industries(9,10). Because of environmental and economic incentives, most large manufacturers practice dust control, usually by means of cloth filters and baghouses(11).

Batch Composition. The basic raw materials for soda/lime container glass are silica sand, soda ash (Na_2CO_3) and limestone (primarily $CaCO_3$, plus some $MgCO_3$ in dolomitic limestones). Feldspar minerals are also utilized as a source of alumina and alkali. Minor amounts of other oxides are introduced as impurities and additional minor ingredients are added for specific purposes discussed later.

Glass sand must be of high purity ($\gtrsim$ 99 percent SiO_2). Primary impurities are Fe_2O_3 and Al_2O_3 which together will be less than 1 percent. The chief sources are unconsolidated bank sand from New Jersey and the standstones of the Alleghenies and the Mississippi valley.

The U.S. supply of soda ash, Na_2CO_3, has changed from predominantly synthetic to natural in recent years. Prior to 1973, more than 60 percent of the domestic soda ash was produced from NaCl by the Solvay process. Now more than half comes from the natural deposits of trona ores (sodium sesquicarbonate, $Na_2CO_3NaHCO_3.2H_2O$). The primary deposits are in Wyoming, but it is also found near Searles Lake and Owens Lake, California.

Limestone is the source of calcium (and magnesium) oxides in the glass batch. This rock has widespread occurrence as either a high-calcium limestone consisting essentially of calcite, $CaCO_3$, or as a dolomitic limestone which is a mixture of dolomite ($CaCO_3 \cdot MgCO_3$) and calcite. Good limestones contain less than 0.1 percent Fe_2O_3 and about 1 percent of silica and alumina. Calcite limestone deposits occur in the central, southern, and eastern U.S. Large dolomitic deposits occur in the central-midwestern parts of the U.S.

Feldspars are anhydrous aluminosilicates containing potassium, sodium, and calcium in varying ratios. They are present in virtually all igneous rocks; but most production comes from pegmatites which are coarsely crystalline rocks formed in the later stages of crystallization of a magma. The principal accessory minerals are quartz, mica, and other silicates. The most critical requirement for glass feldspar is low iron content.

A typical glass-batch composition is(2):

Silica sand	909 Kg	(2000 lb)	(55.6%)
Soda ash	306 Kg	(674 lb)	(18.7%)
Feldspar	118 Kg	(260 lb)	(7.2%)
Limestone	294 Kg	(648 lb)	(18.0%)
Salt cake (Na_2SO_4)	6.8 Kg	(15 lb)	(0.4%)
Total	1634 Kg	(3597 lb)	(99.9%)

Typically, the above ingredients would melt down to 1370 Kg (3020 lb) of glass and give off 259 Kg (569 lb) of gases, primarily (> 99%) CO_2. The batch volume of 1.2 m^3 (42 cu ft) would produce 0.6 m^3 (21 cu ft) of fluid glass and 858 m^3 (30,300 cu ft) of gaseous products (measured at the furnace temperature of 1500 C)(2).

The batch will contain minor ingredients such as salt cake (sodium sulfate) and various fining, coloring, or decolorizing agents. These compounds rarely exceed 5 percent and are often less than 0.1 percent of the total glass composition. Table 6 lists minor ingredients and their effect on the glass.

TABLE 6. MINOR CONSTITUENTS OF CONTAINER GLASS(2,7)

Purpose	Effected By
Amber color	FeS_x (pyrites)
Green color	Cr_2O_3, Fe_2O_3, CuO
Blue color	CoO, FeO, CuO
Decolorization, i.e., Mask Fe_2O_3 color	MnO, Se^{2-}, NiO, Co_3O_4, CeO_2
Fining	SO_4^{2-}, C

Cullet (scrap glass) collected from the plant, purchased on the open market or from recycling centers, is crushed to below 2 cm in size. It is blended with the raw batch in varying amounts. Normally, however, only about 15 to 20 percent of the batch going into a furnace is cullet. If a plant is producing both flint (clear) and colored containers, the cullet must be individually collected and stored to prevent undesirable color fluctuations and to avoid glass foaming conditions caused by mixing amber and flint glass having different oxidation states.

Melting and Fining

The mixed batch is fed into a large continuous-melting furnace where the batch is melted, fined, and conditioned. The melting furnace consists of three distinct regions: the melting end, refiner (conditioning chamber), and forehearth. At the doghouse (batch feeding end of the melting compartment), the raw materials are fed onto a molten mass of glass having a temperature near 1500 C. The batch materials react, melt, and disappear into the liquid glass after floating about one-third to one-half of the length of the melter. As the molten glass moves on through the furnace tank, it is fined, trapped gases (bubbles) are removed, and the melt homogenized.

The glass is essentially free from bubbles when it reaches the end of the melting chamber. Then the glass passes through a submerged refractory throat into a conditioning chamber, popularly called the refiner, where it is cooled to approximately 1300 C. A refractory bridge wall above the throat prevents any glass surface scum from passing into the refiner and also acts as a heat barrier. In the refiner, the glass is cooled to increase its viscosity to the proper working level and to dissolve any remaining tiny bubbles or gaseous inclusions. Then the glass flows through shallow, refractory-lined channels, called forehearths, to the forming machines. In the forehearth, a uniform temperature of the molten glass is maintained. This will be near 1100 C and is adjusted by individual heating and cooling systems. At the end of the forehearth, a stream of molten glass is cut into individual gobs of glass and fed to the forming machine.

Figure 6 is a simplified illustration of a side-port regenerative melting furnace and forehearth. A longitudinal section through the melter and refiner of such a furnace is shown in Figure 7. A transverse section through a forehearth showing the design capability for adjusting glass temperature as it moves to the feeder is shown in Figure 8.

Characteristic dimensions of container glass melting furnaces fall within the following ranges: length 6 to 18 meters (20 to 60 ft), width 3 to 8 meters (10 to 25 feet), and depth 0.6 to 2 meters (2 to 6 feet). The molten glass holding capacity ranges from 36 to 454 Mg (40 to 500 tons), and output 27 to 317 Mg/day (30 to 350 tons/day).

Melting Energy Sources. The glass-container industry predominantly uses regenerative furnaces of side-port or end-port design burning a fossil fuel. In the side-port design commonly used for larger furnaces (> 175 ton/day), combustion products and flames pass in one direction across the top of the molten glass and exhaust through ports on the opposite side of the furnace. In the end-port configuration, combustion products, and flame travel in a horizontal U-shaped path across the surface of the glass within the melter. Fuel and air mix and ignite at one port and discharge through a second port adjacent

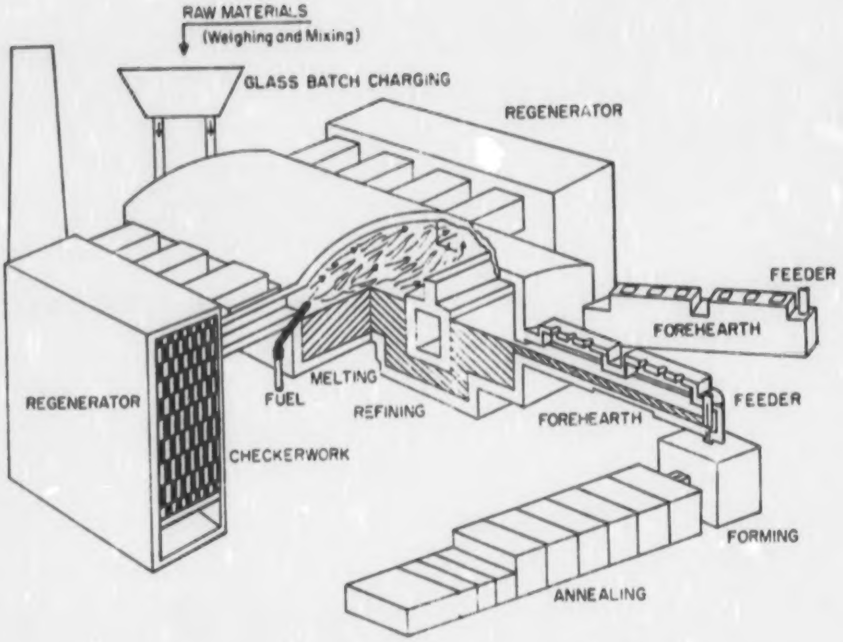
RAW MATERIALS
(Weighing and Mixing)
GLASS BATCH CHARGING
REGENERATOR
FEEDER
FOREHEARTH
MELTING
FUEL
REFINING
REGENERATOR
FOREHEARTH
FEEDER
CHECKERWORK
FORMING
ANNEALING

FIGURE 6. ILLUSTRATIVE SKETCH OF A SIDE-PORT REGENERATIVE-MELTING FURNACE(12)

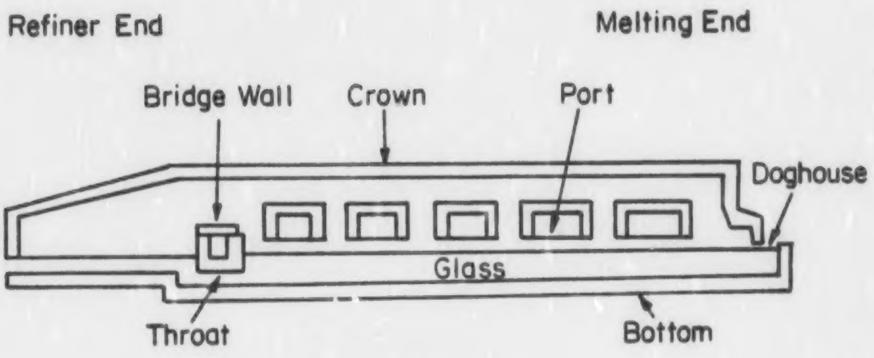
Refiner End
Melting End
Bridge Wall
Crown
Port
Doghouse
Glass
Throat
Bottom

FIGURE 7. LONGITUDINAL SECTION OF A SIDE-PORT REGENERATIVE FURNACE (15)

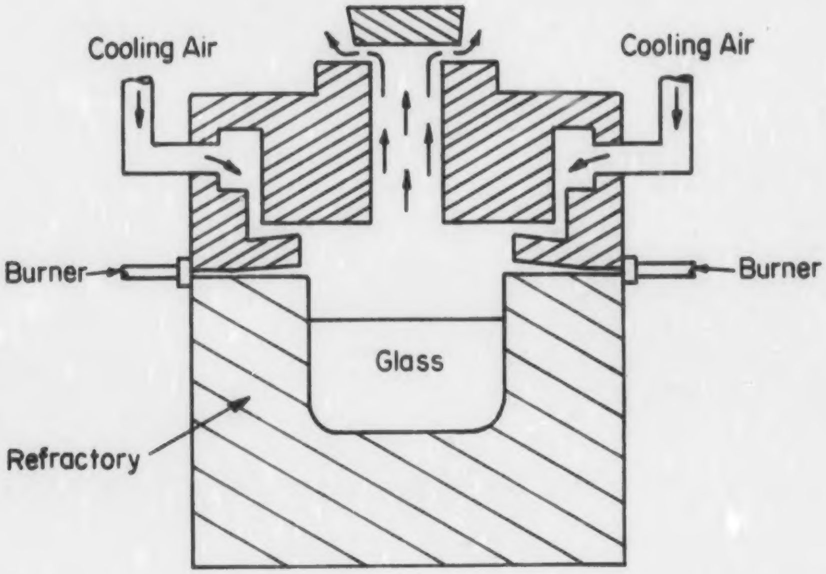
Cooling Air
Cooling Air
Burner
Burner
Glass
Refractory

FIGURE 8. TRANSVERSE CROSS SECTION OF FOREHEARTH (15)

to the first on the same end wall of the furnace. To conserve fuel, the regenerative-firing system is used which employs dual chambers filled with brick checkerwork. While the products of combustion from the melter pass through and heat one chamber, combustion air is preheated in the opposite chamber. The functions of each chamber are interchanged periodically. Reversals occur about every 15 to 20 minutes as required for maximum conservation of heat. Figure 9 is a cross section of a side-port regenerative furnace. The regenerators are about two stores tall and are positioned on each side of "side-port" furnaces or at one end of "end-port" furnaces.

The glass container industry has historically used natural gas as the primary energy source. In 1971, over 83 percent of the energy was derived from the combustion of natural gas(15). In more recent years, the limited availability of natural gas has resulted in a shift to greater use of fuel oil. In 1975, the energy supplied by natural gas was between 70 and 75 percent(2).

Since molten glass is an electrolyte, it can also be heated electrically. Such heating is used primarily to supplement fossil-fuel heating, rather than replace it and is referred to as electric boosting. One estimate indicated that approximately 40 percent(15) of all furnaces now have electric boosters. Less than 5 percent of container glass furnaces in the U.S. were heated entirely by electricity in 1974(15).

Future energy sources could vary considerably from the present-day pattern depending upon the availability and cost of fossil fuels.

Melting-Furnace Emissions. Exhaust gases from the melting furnace are major sources of air pollutants from the glass container manufacturing process. Emissions primarily include NO_x, SO_x, and particulates. Nitrogen oxides (predominately NO) are formed by the reaction of atmospheric nitrogen and oxygen under the higher temperature conditions of the furnace. Sulfur oxides (predominately SO_2) come from the decomposition of sulfates in the melt and, where fuel oil is used for heating, from the combustion of sulfur in the fuel. Particulate emissions may arise from: (1) volatilization of materials in the melt which subsequently condense in the checkers or stack, or (2) to some extent by

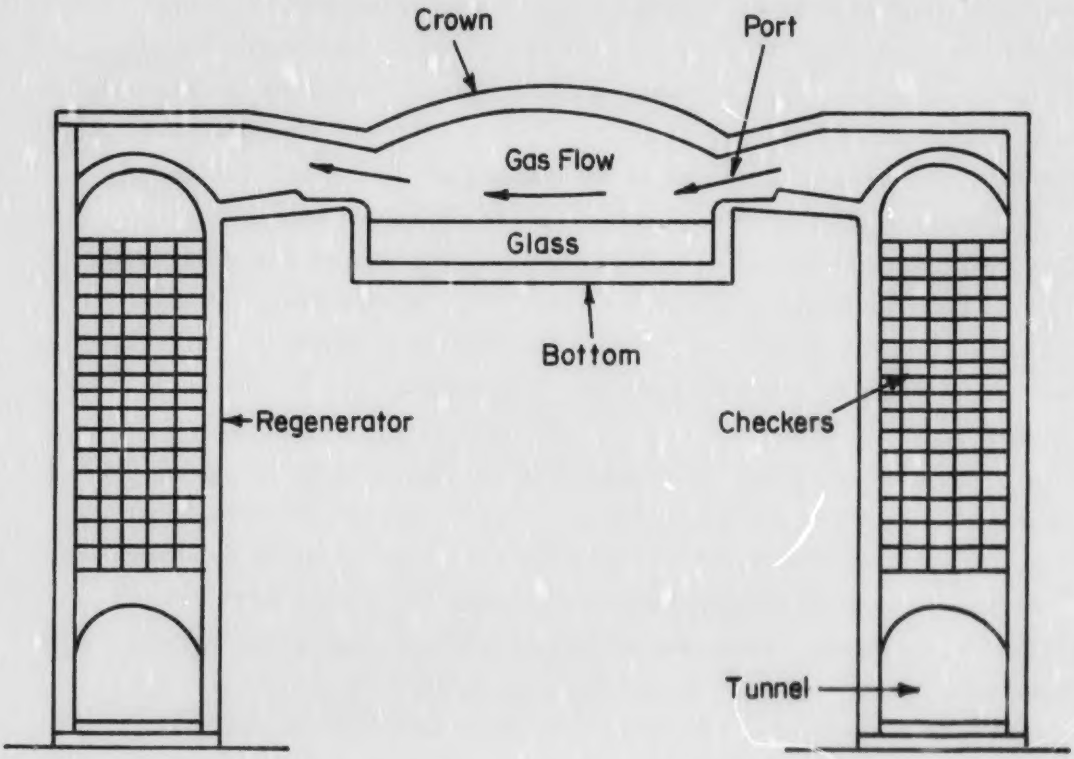
Crown
Port
Gas Flow
Glass
Bottom
Regenerator
Checkers
Tunnel

FIGURE 9. CROSS SECTION OF SIDE-PORT REGENERATIVE FURNACE(15)

physical entrainment of batch dust in combustion gases(13). Batch constituents which can contribute to volatilization are predominately alkali sulfates and other minor constituents such as selenium.

Forming

The forming of glass containers by industry's highly mechanized equipment involves several steps.

- The molten glass is cut into gobs by a set of shears as the glass leaves the forehearth.
- Delivery equipment directs the gobs into blank molds.
- In the blank mold, the gob is partially shaped into a parison. This task is performed predominantly by an air-blowing process for narrow-neck containers, but it may also be performed by pressing. For wide-neck containers, it is performed by pressing.
- The parison is then inverted and transferred into a blow mold.
- The parison is blown into final shape with compressed air.

The process of forming narrow-neck containers in which the parison is formed by blowing steps is illustrated in Figure 10.

Most glass containers are formed on individual section (I.S.) machines which may be designed with up to 10 sections per forming machine and may have maximum speed capabilities exceeding 200 containers per minute.

In the operation of the forming equipment, coolants and lubricants are employed. Water-based sprays are used to cool the shears which cut the glass gobs. Delivery equipment which directs glass gobs into the blank molds may be sprayed with lubricating emulsions of hydrocarbon- or silicone-based materials, and metal molds are commonly lubricated with mixes of graphite, greases, oils, etc.

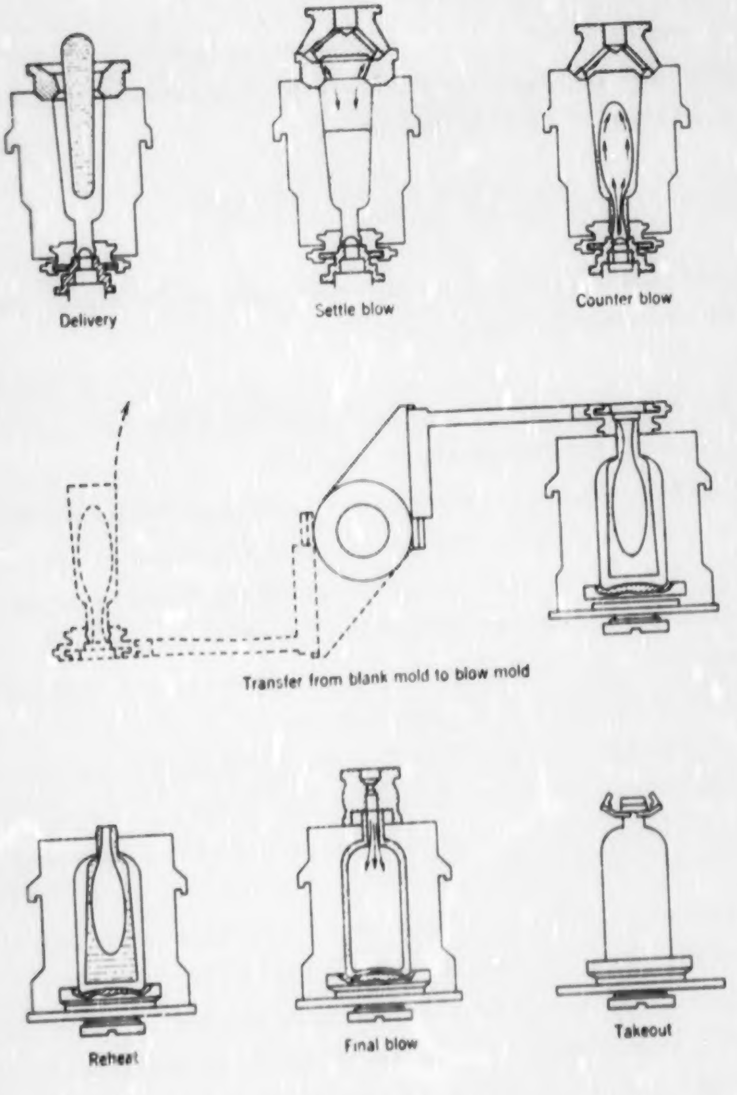
Delivery
Settle blow
Counter blow
Transfer from blank mold to blow mold
Reheat
Final blow
Takeout

FIGURE 10. ILLUSTRATION OF THE I.S. BLOW-AND-BLOW PROCESS FOR FORMING NARROW-NECK CONTAINERS(7)

Postforming

This step can consist of many operations, depending on the product requirements. These include surface treatments, annealing, decorating, and coating.

Surface treatment with titanium or tin chloride may be applied to hot containers as they are transported along conveyors between the forming machine and annealing oven. The metal chloride reacts to yield titanium or tin oxide on the glass surface and releases HCl. The surface oxide greatly increases the container scratch resistance and thus produces containers of higher service strength.

The primary step, through which all newly formed containers pass, is annealing. Annealing is necessary to remove stresses that will weaken the glass or cause it to fail. In this step, the entire piece of glassware is brought to a uniform temperature high enough to permit the release of internal stresses (590 to 650 C) and then cooled at a uniform rate to prevent new stresses from developing. Annealing is done in long continuous furnaces called lehrs.

Following annealing, but while the containers are still hot (about 100 to 150 C) and on the lehr conveying belt, they may receive additional surface treatment. Water-based emulsions of polymer or organic materials are most commonly sprayed onto the hot bottles. The latent heat of the bottles evaporates the water and bonds the organic which yields a lubricious container surface. This surface lubricity minimizes or prevents jamming of bottles as they move along in line conveyors and reduces surface damage.

After annealing (and surface treating, if applied), containers are visually and optically/mechanically inspected. In addition, cylindrical bottles to contain pressurized products may be "proof tested" by applying an internal air pressure, and/or passing them between rubber belts or rollers which squeeze the bottle. Carbonated beverage bottles are also statistically sampled and subjected to destructive-burst tests.

Decorations or labels may also be applied to containers in the production plant. For beverage bottles, screen-printing processes may be employed for some bottles to apply organic resins or vitrifiable glass colors, although other techniques and materials may be used. Only a small portion, about 3 percent, are decorated.(2)

Containers, especially for carbonated beverages, may also be coated with plastic. Such coatings or sheaths may serve one or more functions. They may reduce bottle-to-bottle handling damage, reduce filling-line noise, serve as labels, or provide containment in the event of fracture of a pressurized beverage container. These coatings reportedly may be applied by: wrapping and heat-shrink techniques, electrostatic-powder applications, dip-coating, or other methods(12). Only a small percentage (< 5%) of containers are currently plastic coated, but this percentage may increase in the future.

SECTION IV

EMISSIONS

Emissions from glass-container plants are categorized according to three operations within the manufacturing process

- Particulate emissions from the raw-materials handling, preparation, and transfer.
- Gaseous and particulate emissions from the glass-melting furnace. These contain SO_x, NO_x, submicron sodium sulfate condensates, hydrocarbons, CO, and other minor emissions such as selenium.
- Gaseous and particulate emissions from a variety of forming and postforming operations. These result from annealing, decorating, surface treatment, and coating operations and can include particulates (e.g., SnO_2), hydrocarbons, NO_x, and SO_x.

This section describes the various emissions, characteristics, their levels, total quantities, and environmental effects. The information is organized according to the three sources within the manufacturing process.

- Raw-materials preparation and handling
- Glass melting
- Forming and finishing.

Raw-Materials Preparation and Handling

Typical points of particulate emissions during raw-materials preparation and handling are shown in Figure 11. These points include

- Unloading and conveying
- Crushing of cullet (scrap glass)
- Filling and emptying of storage bins
- Weighing and mixing of batch
- Feeding of batch to glass furnace (batch charging).

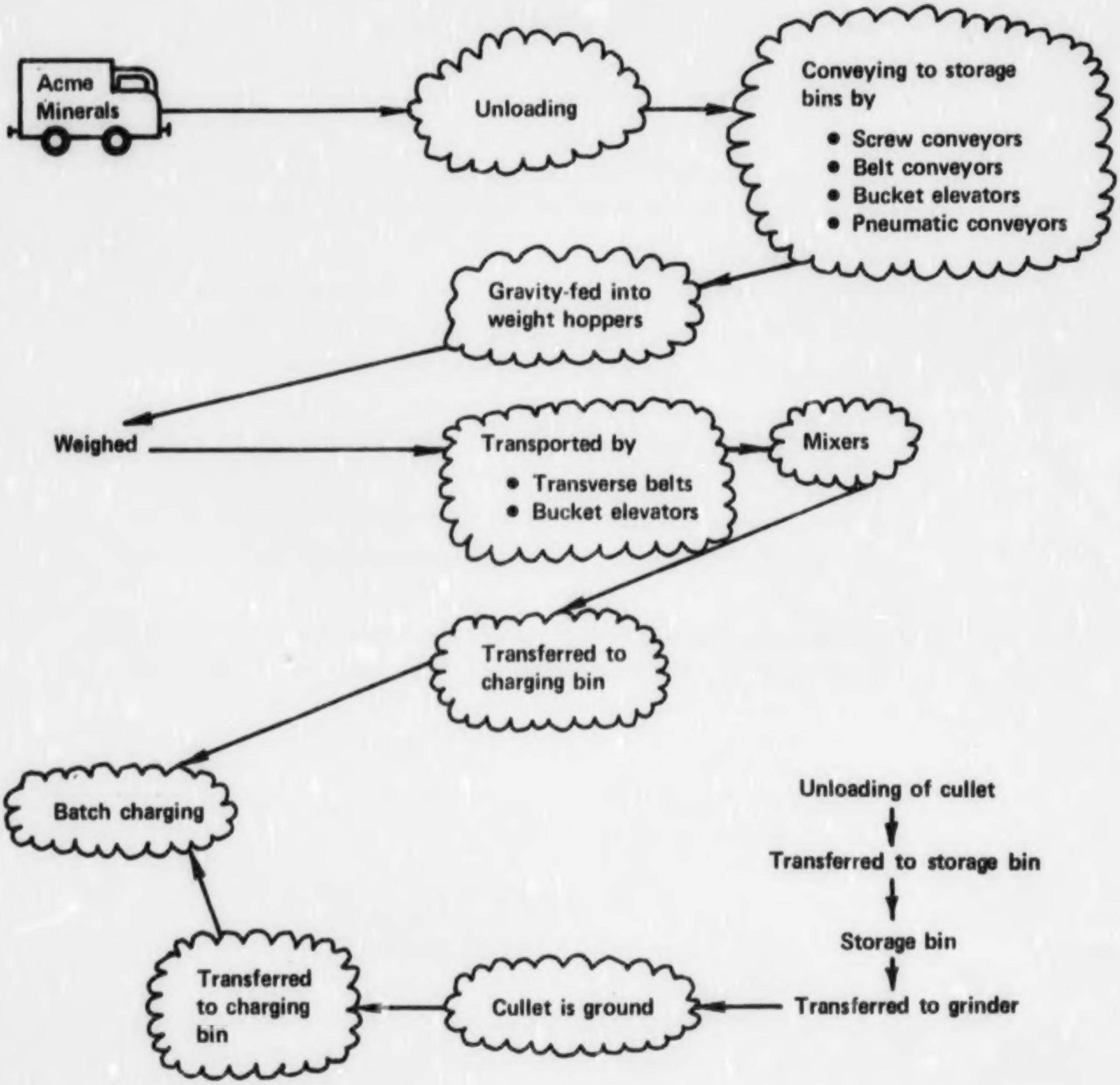
Acme
Minerals
Unloading
Conveying to storage bins by
• Screw conveyors
• Belt conveyors
• Bucket elevators
• Pneumatic conveyors
Gravity-fed into weight hoppers
Weighed
Transported by
• Transverse belts
• Bucket elevators
Mixers
Transferred to charging bin
Batch charging
Unloading of cullet
Transferred to storage bin
Storage bin
Transferred to grinder
Cullet is ground
Transferred to charging bin

FIGURE 11. TYPICAL POINTS OF PARTICULATE EMISSION FROM RAW-MATERIALS HANDLING

All of these are potential sources of particulate emissions; however, those particulates which remain in the manufacturing plant may constitute an OSHA health and safety consideration distinct from plant emissions. For the purposes of this study, fugitive-dust emission was defined as particulate emissions that result from industrial-related operations, and which escape to the atmosphere through windows, doors, vents, etc., but not through a primary exhaust system, such as a stack flue, or control system. This definition is derived in part from a paper presented by Lillis and Young of the U. S. Environmental Protection Agency(16). Information obtained from ambient sampling up-wind and down-wind of the manufacturing facility is the preferred source of data. If actual data from high-volume samples are not available, engineering estimates based on the particle size of raw material which can contribute to dust emissions are desired. For the purposes of this study, the particle size range of the raw materials which will be considered as contributing to fugitive dust emissions was 100 microns or less in diameter. This definition of dust is not as broad as the technical definition given by Stern(17), but this particle-size distribution seems reasonable for glass-manufacturing processes. The settling velocity of a 100-micron-diameter sphere, with a specific gravity of 2.0 g/cc, is approximately 50 cm/sec in still air at 25 C and 1 atm. Such a settling rate is sufficiently slow that the emission of dust from a tall source, such as the raw materials storage bins, would probably contribute to the total air emissions.

Fugitive dust is usually emitted during unloading and conveying operations. To minimize dust emissions, these operations are generally enclosed and the vents on storage bins and mixers exhausted through fabric filters. Batch wetting, or the addition of water to the batch during the mixing operation, is another practice commonly used which minimizes particulate emissions. As a result, limited data on particulate emissions from stacks are available and no data were available on fugitive dust. Particulate-emission data from point-source measurements were reported in NEDS(14) (National Emission Data System) and are given in Appendix B. Although these particulate emission data were not broken down into specific ingredients, these data enable the calculation of overall average emission factors for raw-materials handling and preparation on a worst-case basis. The overall emission rate is determined to be 29 mg/kg ± 100 percent. Total annual particulate emissions for raw-materials handling and manufacturing are 459 Mg ± 100 percent. This is based on 12.7 Tg of glass produced, and is equivalent to 0.0003 percent of the national particulate emissions from stationary sources.

Table 7 shows a breakdown of raw-materials handling for the various points of emission. This was determined primarily by NEDS data(14), and confirmed by observations made during plant visits.

Most materials used to make glass containers have specified particle size limits greater than 100 microns (150 mesh). Therefore, the amount of material emitted from the plant site due to inertial forces will be minimal. Composition of the particulates is given in a later section.

Glass Melting

Container glass is predominantly melted in fossil-fuel-fired furnaces in the United States. Emissions from these furnaces are by far the largest source of pollutant from a glass plant. Primary pollutants are categorized as NO_x, SO_x, and particulates. The NO_x is composed predominately of NO and the SO_x composed predominately of SO_2. Emissions of CO, hydrocarbons, selenium, and other materials can and do occur. The emission rate does depend to some degree on glass type (i.e., flint or amber glass).

The overall emission rates and total emissions for furnaces melting flint and amber glasses are given in Table 8 as well as in Appendix B. The emission factors are based upon data reported in NEDS(14) and derived from various literature sources(13, 18-19). Data referred to as source measurements, reported in NEDS, were obtained by actual point source test measurements. The emission rates depend a great deal upon the operating conditions of the glass-melting furnace. For instance, NO_x emissions factors are reported to range from 0.58 g/kg to 6.29 g/kg, SO_x from 0.21 g/kg to 8.35 g/kg, and particulates from 0.13 g/kg to 1.95 g/kg. Each type of emission is discussed in greater

TABLE 7. PARTICULATE EMISSIONS DURING RAW-MATERIAL PREPARATION AND HANDLING FOR CONTAINER GLASS

Process Step	Emission Factor, mg/kg	Total Annual Emissions[(a)], Mg
Handling (unloading, conveying	22 ± 100%	348
Glass crushing	1 ± 100%	16
Storage bins	1 ± 100%	16
Mixing and weighing	5 ± 100%	79
Batch charging	Negligible[(b)]	
TOTAL	29 ± 100%	459

(a) Based on 15.8 Tg of raw materials processed to melt 12.7 Tg of glass.

(b) <0.1

TABLE 8. EMISSIONS FROM FLINT AND AMBER CONTAINER GLASS-MELTING-FURNACE OPERATIONS

Species	Emission Factor, g/kg			Total Annual Emissions Based on Glass Manufactured[(a)], Gg			Percent of National Emissions from all Stationary Sources		
	Flint	Amber	Total	Flint	Amber	Total	Flint	Amber	Total
NO_x	3.40 ± 43%	1.22 ± 100%	3.07 ± 47%	36.57	2.32	38.89	0.3179	0.0199	0.3378[(a)]
SO_x	1.84 ± 36%	0.93 ± 100%	1.70 ± 42%	19.79	1.76	21.55	0.3073	0.0028	0.3101
Particulates	0.71 ± 30%	0.48 ± 100%	0.68 ± 36%	7.64	0.91	8.55	0.0062	0.0006	0.0068
CO	0.06 ± 166%	0.11 ± 100%	0.07 ± 143%	0.65	0.21	0.86	0.0036	0.0011	0.0047
Hydrocarbons	0.08 ± 100%	0.05 ± 100%	0.08 ± 100%	0.65	0.09	0.74	0.0024	0.0003	0.0027
Selenium	0.002 ± 100%	0	0.002 ± 100%	0.02	0	0.02	--	--	--

(a) 10.758 TG for flint, 1.898 TG for amber, 12.656 TG total, assuming a pack rate of 85 percent.

(b) Standard for NO_2.

detail for both flint and amber glasses. As was shown previously (Figure 3), flint and amber glass comprises approximately 85 percent and 15 percent, respectively, of the glass produced in the United States. Green glass is included in flint. No differences in emissions are expected between green and clear glasses.

Nitrogen Oxides

In a fossil-fuel-fired furnace, nitrogen oxides are formed by a combination of atmospheric nitrogen and oxygen at the elevated temperatures (> 1500 C) required for making glass. Because of the high temperature, NO would be expected to be the primary oxide of nitrogen formed. For purposes of this analysis, nitrogen oxides are designated as NO_x. In this study, NO_x is compared against an NO_2 air quality standard. The assumption that the NO_2 emission factor is equal to the NO_x emission factor is believed valid, because once the plume has been diluted sufficiently with air (dispersion calculations show that the plume is diluted approximately 1000 to 1 at the point where it touches the ground), the photochemical conversion of NO to NO_2 is quite rapid.

Nitrogen oxides represent the largest fraction by mass ($\sim$ 54%) of emissions from the glass-melting furnace. The formation of NO_x in a glass-melting furnace is extremely temperature sensitive. In one case, NO_x concentration was increased some six times (from 100 ppm to $\sim$600 ppm) as the furnace temperature (measured at the bridgewall) increased from 1460 to 1550 C and the flint glass production rate was doubled(18).

The rate of NO_x formation depends upon factors such as peak flame temperature, percent excess oxygen, and posttime/temperature history of the flame. Consequently, considerable variation in the rate of NO_x emissions can and does occur.

This report considers all nitrogen oxides as NO_x and does not attempt to determine the relative proportions of each. This differs from that method preferred by the Glass Packaging Institute (GPI). Copies of correspondence from GCMI (now GPI), EPA, and Battelle relating to this point as well as other points are given in Appendix G.

Flint Glass. Source measurements reported in NEDS and taken from the open literature give an average emission rate of 3.40 g of NO_x per kg of flint glass produced. This average is based on 21 measurements (see Appendix B) and is calculated to be accurate to within ± 43% at a 95 percent confidence level. Individual values range from 0.58 to 6.29 g/kg. This amounts to approximately 36.6 Gg of NO_x emitted annually from furnaces melting flint container glass. This is equivalent to 0.32 percent of 1972 National NO_2 emissions from all stationary sources(20).

Amber Glass. Only three source measurements were found for NO_x emissions from furnaces producing amber glass. These gave an average emission rate of 1.22 g of NO_x per kg of amber glass produced. There is no reasonable way to assign an accuracy to these numbers. The average, however, is lower than for flint. Individual NO_x values were 1.21, 1.24, and 1.22 g/kg. The estimated annual NO_x emissions from furnaces melting amber container glass would be 2.32 Gg or approximately 0.02 percent of 1972 National NO_2 emissions from all stationary sources(20).

Sulfur Oxides

Sulfur oxide emissions occur through both the decomposition of sulfates (e.g., Na_2SO_4) added in the glass batch and from the oxidation of sulfur in the fossil fuel. When oil is used as the fossil fuel, the largest majority (> 80 percent) of sulfur oxide emissions are derived from sulfur in the oil.(5) Sulfur oxides from the batch generally combines with alkali volatiles and exits as a particulate, while sulfur in the fossil fuel exits predominately as SO_x.

Glass generally contains about 0.15 weight percent sulfate (added usually as salt cake, gypsum, or blast-furnace slag). This is added for melting and fining purposes and is a necessary ingredient for making container glass. A range of values for sulfate ($SO_4^=$) in glass was reported in 1973 as varying from 0.03 to 0.32 percent, with 82 percent of some 106 glasses analyzed falling between 0.10 and 0.20 percent(15). The amount of mineral sulfate added in the batch will, of course, be higher and usually falls within the 0.5 to 1.0 percent range. Sulfur oxide emissions from the batch materials do occur(18) and these depend primarily upon the quality of glass melted.

Sulfur oxide emissions will be greatly influenced by any switch from natural gas (the primary fossil fuel), which is essentially sulfur-free to fuel oils or powdered coal containing sulfur. Such a trend does exist primarily because of the reduced availability of natural gas in most sections of the country. Sulfur in fossil fuels readily oxidizes in the glass-melting furnace and appears as SO_x in the exhaust gases. For instance, a fuel oil containing one weight percent sulfur emits approximately 600 ppm (calculated as SO_2) in the flue gas(21).

Source measurements reported in NEDS or in the literature are essentially for natural gas-fired furnaces. Hence, the emission are not fully representative of an industry which is gradually switching to fuels containing sulfur. However, such emissions will essentially correspond directly to the sulfur found in the fuel oil.

Flint Glass. Source measurements for flint glass give an average SO_x emission rate of 1.84 g/kg. This is based on 46 point source measurements (see Appendix B) and is calculated to be accurate to within ± 0.36% at a 95 percent confidence level. The values ranged from 0.21 to 8.35 g/kg. This gives an estimated total annual emission of SO_x of 19.8 Gg, which is equivalent to 0.31 percent of 1972 National SO_x emissions from all stationary sources(20).

Amber Glass. Again, data were only available from three sources for furnaces melting amber glass. These gave an average SO_x emission rate of 0.93 g/kg. The three values were 0.32, 2.06, and 0.41 g/kg. As can be seen, these values are essentially equivalent to those for flint glass. Total annual SO_x emissions from furnaces melting amber glass are estimated to be 1.76 Gg which is 0.003 percent of 1972 National SO_x emissions from all stationary sources(20).

Particulates

Particulates from glass-melting chamber can originate both from physical entrainment of batch materials being charged to the melting furnace and from condensation of compounds, such as sodium sulfate (which forms through the combination of sulfur oxides and volatilized sodium). Particulates exiting with exhaust gases are essentially all (>95 percent) condensates, as indicated by the fact that collected material is almost entirely water soluble. Studies do show that batch materials are carried out of the melting chamber by the combustion products; however, such materials do not show up in the stack-gas samplings; therefore, it is assumed these coarser batch materials are retained in the furnace-flue system.(22,23,24)

Considerable opinion exists as to the mechanism by which condensate particles are formed; however, analysis of these particulate emissions show them to consist predominately (>75 percent) of submicron sodium sulfate(9,18,22-24).

The formation of these particulates depend upon batch composition, temperatures in the melting furnace, production rate, surface area of molten glass, and cullet ratio. Of these factors, production rate, temperature, and surface area of molten glass are the most important factors affecting the rate of particulate emissions. Since these variables are interrelated, it is difficult to determine the relative influence of each, although it would appear that temperature is the most significant variable. Data from one furnace melting a soda lime glass showed that at zero production rate, the particulate emissions were approximately 20 percent of that measured at its normal furnace capacity(18).. Temperature was maintained at a constant value (1450 C). Emissions ranged from 1.8 kg/hr at zero pull to 7.7 kg/hr at normal pull of 211 Mg/day. Other data(18) collected on soda/lime glass during the study indicated that particulate emissions followed an Arrhenius curve when plotted against the reciprocal of temperature; that is, a linear relationship with the logarithm of the emission rate. This is shown in Figure 12.

Stockham and others(24-25) studied the emissions from furnaces melting a flint and an amber glass and found the geometric mean particle size of the particulate emissions to be 0.13 micron for the flint and 0.11 micron for the amber.

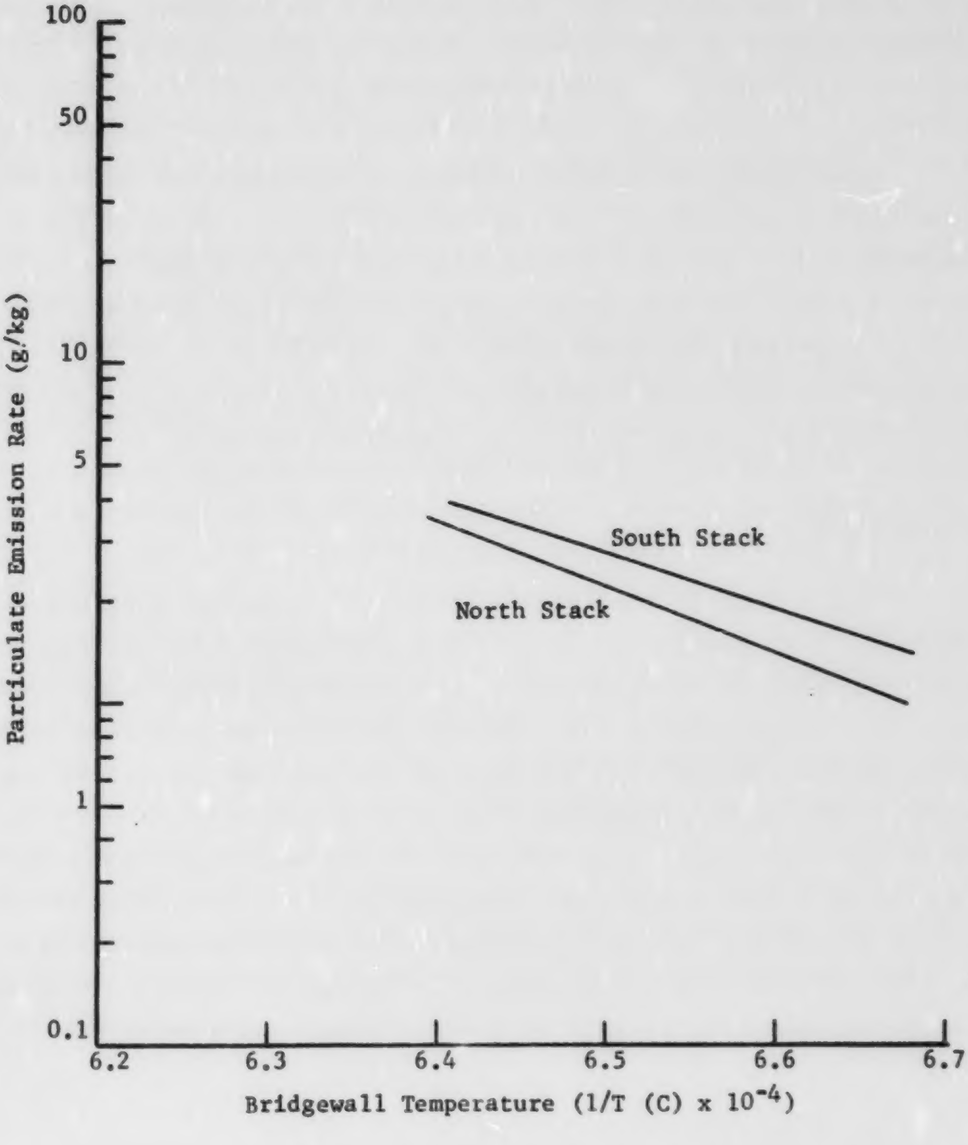

FIGURE 12. PARTICULATE EMISSIONS SHOWN ARE LINEAR WITH THE RECIPROCAL OF BRIDGEWALL TEMPERATURE

Flint Glass. Source measurements for particulate emissions from flint glass-melting furnaces give an average emission rate of 0.71 g/kg. The emission rate varied from 0.22 g/kg to 1.95 g/kg. Source measurements were taken from 66 points and are calculated to be accurate within ± 30% at a 95 percent confidence level. This represents an estimated total annual particulate emission of 7.64 Gg, or 0.006 percent of the 1972 National particulate emissions from all stationary sources(20).

Amber Glass. Source measurements for particulate emissions from furnaces melting amber glass give an average emission rate of 0.48 g/kg. The emission rate varied between 0.13 g/kg and 0.83 g/kg. The average is based on 23 source test measurements and is calculated to be accurate within ± 41% at a 95 percent confidence level. This represents an estimated total annual particulate emission of 0.91 Gg or 0.001 percent of the 1972 National particulate emissions from all stationary sources(20).

Carbon Monoxide

Carbon monoxide can be emitted through incomplete combustion of the fossil fuel through the use of a luminous flame, or by reaction of a powdered coal added to the glass batch to reduce sulfate compounds. The emission rate varied between 0.05 and 0.13 g/kg. An estimated emission rate for flint glass is 0.06 g/kg, based upon 19 reported measurements and accurate to within ± 167% at a 95 percent confidence level. This would represent an annaul emission of 0.65 Gg of CO, or 0.004 percent of 1972 National CO emissions from all stationary sources(20). Only three source measurements are available for amber glass. These show an emission rate of 0.12, 0.10, and 0.09 g/kg for an average of 0.11 g/kg. This would represent an annual emission of 0.21 Gg for CO from furnaces melting amber glass.

Hydrocarbons

Hydrocarbon emissions form in glass-melting furnaces primarily through the incomplete combustion of a fossil fuel. The emission rate varied from 0.01 to 0.53 g/kg. An estimated average emission rate for flint glass is 0.08 g/kg, based upon 33 measurements calculated to be accurate within ± 100%. Such an emission rate represents an annual emission of 0.65 Gg of hydrocarbons by manufacturers of flint glass, or 0.002 percent of 1972 National emissions for hydrocarbons from stationary sources(20). Only three measurements were available for amber glass. These are 0.06, 0.03, and 0.05 g/kg, which give an average emission rate of 0.05 g/kg or total annual emission of 0.09 Gg.

Selenium

Selenium is used by flint glass manufacturers as a decolorizer to neutralize the tint from transition metal oxide contaminants such as iron. It is usually used in amounts of up to 0.001 percent. Test measurements on selenium emissions were not found. Selenium volatilizes at rather low temperatures (315 C for SeO, 685 C for Se)(9,22); therefore, it can be expected to be present in the waste gases. If the temperature of the waste gases is dropped below 200 C, then selenium condensates are likely to be found.

The maximum amount of selenium release can be determined from the amount of selenium consumed annually by the glass container industry. A minimum of 60 percent is retained in the glass.(32) Some 0.06 Gg of selenium is consumed annually by the glass container industry (about one-sixth of U. S. usage).(2) Under these circumstances, which is believed to be a worst case, the emission rate for selenium would be 0.002 g/kg. Total annual emissions would be 0.02 Gg.

Other Emissions

Other minor emissions can include antimony and arsenic, which in the past were added as fining and decolorizing agents. Both of these materials have been virtually eliminated from use in recent years. Similarly, chlorine was emitted in the past because of its association with soda ash produced by the Solvay process. In recent years, most of the glass-container industry has switched from soda ash produced synthetically to that manufactured from a naturally occurring ore which does not contain Cl. By 1977, more than 90 percent of the industry will be using natural soda ash(9,26).

Forming and Finishing

Molten glass, properly conditioned, leaves the forehearth of the melting furnace, where it is cut into individual "gobs", which are then transferred to the forming machine. The gob is formed into a container by the blow-and-blow or press-and-blow method. After forming, a hot-end coating or surface treatment may be applied, followed by the annealing operation. Following this, the containers may then undergo a variety of decorating or coating operations.

Emissions from the forming and finishing operations can include hydrocarbons emitted during the forming operations, HCl and metal oxides emitted during surface-treatment operations, emissions associated with combustion gases produced during annealing, and organic fumes emitted from the coating and decorating operations.

Very little emission data are available from the forming and finishing operations. This section discusses emissions according to four operations: forming, treatment, annealing, and decorating.

Forming

Gob shears, delivery chutes, and the forming molds for container glass are lubricated with various solutions. These solutions can contain grease, oils, graphite, and silicon-based emulsions. In the past decade, there has been a transition from grease and oil lubricants to the use of silicone-emulsions and water-soluble oils (1 part silicone or oil to 90-150 parts water) on gob shears and gob-delivery systems(9). Grease and oils are still utilized on molds. Observing the forming operation, one can frequently see a puff of white smoke occur when the molds are swabbed with a lubricating solution. Although the smoke dissipates in a few seconds, hydrocarbon vapors are probably released. These emissions are probably drawn through the large ventilators on the roof of the plant. Emission data on hydrocarbon emissions was not available; however, engineering calculations (Appendix B) indicate that the maximum emission rate is low (0.03 g/kg). Total emissions are estimated to be 0.44 Mg or less than 0.0001 percent of National Emissions.(20)

Surface Treatment

Some glass containers receive a metal oxide (titanium or tin) surface treatment to improve their resistance to scratching. Additionally, this transparent treatment acts as a lubricant which can facilitate handling and shipping operations. The oxide treatment is obtained by subjecting the hot container (coming from the forming machine) to a vapor of metal chloride. This is done within a hood. The metal chloride pyrolyzes to the metal oxide on the container surface, leaving a metal-oxide film and releasing hydrogen chloride. The bottles then go to the annealing oven.

Emissions from the surface-treatment operation will consist of HCl, metal oxides, and hydrated-metal chlorides. Anhydrous tin chlorides which do not react with the glass will decompose by the action of heat and moisture within the exhaust ductwork to form metal oxides, hydrates metal chlorides, and HCl. Estimations based upon available data(2,14) indicate that approximately 60 percent of the total weight of the metal chloride input is released into the atmosphere. Using tin tetrachloride as the input material, these estimations reveal that of the total weight input, 14 percent is released into the atmosphere as a metal oxide, 27 percent as hydrated tin chloride, and 21 percent as HCl.

Emissions from the surface-treatment operation were determined by engineering calculation to be 0.02 g/kg of tin or titanium oxide, 0.03 g/kg of hydrated tin or titanium chloride, and 0.02 g/kg of HCl. Total emissions are estimated to be

0.08 Gg of metal oxide, 0.11 Gg of hydrated metal chloride, and 0.08 Gg of HCl annually. This estimate is based on 30 percent of the containers being treated.(2)

Annealing

All glass containers undergo an annealing operation, where the glass is brought to a temperature (approximately 550 C) to remove residual stresses and then cooled uniformly to about 150 C where they are removed from the annealing lehr (oven). All lehrs used by glass container manufacturers are heated by natural gas, with propane as a possible alternate fuel.

The only emissions from annealing lehrs are combustion products. Since natural gas is used exclusively, although lehrs can be heated electrically and the temperatures are relatively low, emissions are low. Measurement data are not available and emission rates were estimated on the basis of emission factors for the combustion of natural gas. The results are given in Table 9. Total emissions were calculated on the worst case basis of all product being annealed in gas-fired lehrs.

Decorating

Glass containers are sometimes decorated with vitrifiable glass enamels or organic materials. A wide variety of decorating techniques are employed. Emissions occur predominately from organic solvents and binders used in decorative coatings which are released during the curing of these compounds. Data supplied by three glass container manufacturers would indicate that only 3 percent of all (both flint and amber) containers have decorative coatings. This amounts to 330 Gg of container glassware decorated annually. Based upon 5 material balances given in NEDS(14), a hydrocarbon emission rate of 4.37 g/kg was determined for container decorating. No point source measurements were available. This amounts to 1.44 Gg of HC emitted annually. This represents 0.005 percent of the National HC emissions from all stationary sources.(20)

TABLE 9. EMISSIONS FROM THE ANNEALING OF SODA/LIME CONTAINER GLASSES

Species	Emission Factor g/kg	Emission Factor (lb/ton)	Total Annual Emissions[(a)], Gg	Total Annual Emissions[(a)], (ton)	Percent of National Emissions from all Stationary Sources
NO_x	0.0015	(0.003)	0.019	(21)	0.0002
SO_x	0.025	(0.05)	0.316	(329)	0.0005
Particulates	0	0	-	-	-
CO	0	0	-	-	-
Hydrocarbons	0.035	(0.07)	0.443	(488)	0.0017
Total					

(a) Based on 12.656 Tg of glass processed.

Emission Characteristics

Raw Materials Preparation

Emissions from this part of the manufacturing process will reflect the raw materials used soda ash, limestone, feldspar, sand and sodium sulfate), since no chemical reactions take place. Soft materials like limestone and soda ash will be more easily crushed to dust.

Manufacturers generally specify particulate sizes ranging from 820 to 44 micron (-20 to +325 mesh). Table 10 illustrates general specification limits for several raw materials used to make glass containers. Glass sand would not be expected to cause significant dusting since only a small fraction is below 100 micron and all particles are greater than 44 micron.

The primary ambient air standard for particulates is 260 $\mu g/m^3$.

Glass Melting

Emissions from the melting furnace consist of the criteria pollutants: NO_x, SO_x, particulates, CO and hydrocarbons, as well as selenium. These emissions contribute to photochemical atmospheric reactions to produce smog and can be irritating to the lungs.

Particulates consist predominately of sodium sulfate (>85 percent). It is unclear as to whether these sulfate emissions pose a health hazard(30).

Forming and Finishing

Emissions from the forming and finishing operations consist of the following:

(1) NO_x, particulates, CO, and hydrocarbons emitted from gas-fired annealing lehrs.

(2) Hydrocarbons produced by flash vaporization of mold lubricants used in forming glass containers.

(3) HCl, tin or titanium oxide, and hydrated metal chlorides exhausted from fume chambers during surface treatment operations.

TABLE 10. GENERAL SPECIFICATION LIMITS FOR RAW MATERIALS USED IN CONTAINER GLASS MANUFACTURE

Mineral	Chemical Formula	Material Specifications Range Amount, %	Mesh*	Amount, %	Mesh*
Cerium oxide	CeO_2	-	-	100	-60
Dolomite	$(Ca,Mg)CO_3$	0.5	+16	50	-100
Feldspar	-	2	+40	10	-200
Limestone	$CaCO_3$	0.2	+20	0.5	-300
Sand	SiO_2	3	+30	6.6	-100
Soda ash	Na_2CO_3	0	+20	4.2	-120
Sodium Nitrate	$NaNO_3$	1	+6	1.5	-100

* U. S. standard mesh size - see Table 15 for micron equivalents.

(4) Hydrocarbons produced during the curing of decorative coating used on some glass containers.

Total nationwide emission of the criteria pollutants produced in the different stages of the container glass-manufacturing process were listed previously in Table 2.

At a glass plant, the major amount of atmospheric emissions comes from the melting furnaces. Calculations to portray the effect which a glass plant has on its neighboring air environments have been made in the following sections. Principal attention has been given to the pollutants issuing from the melting furnace stacks.

Ground-Level Concentrations

Ground-level ambient concentrations of pollutants were used in determining the environmental effects of the atmospheric emissions. These were calculated for representative operations used in the manufacturing of glass containers. A single plant having an annual production of 104.8 Gg (115,000 ton) was selected as being representative, following the calculations made in earlier portions of this report.

Stack heights for container-glass furnaces, as given in the NEDS listing, ranged from 5 to 50 meters with the predominant height being about 40 meters. Two other frequently occurring stack heights are in the vicinity of 20 m and 45 m. There is no correlation between stack height and production rate. In general, stacks taller than 30 m can be assumed as natural draft stacks or natural draft stacks that have been converted to an ejection-air system. A mean stack height of 38.2 m (125 ft) was selected for the melting furnaces in a representative plant. Other stack parameters are chosen from the NEDS data for their compatibility with a 38 m stack. The furnace-stack emissions are derived from the emission factors given in Table 2 and are applied to the 104.8 Gg annual production rate. All of the parameters for the melting furnaces and stacks are listed in Table 11.

The maximum ground-level concentration was used to determine information for the environmental effects criteria. This maximum concentration can

TABLE 11. PARAMETERS FOR MELTING FURNACES OF A REPRESENTATIVE PLANT IN THE GLASS-CONTAINER INDUSTRY AS USED IN ATMOSPHERIC-DISPERSION CALCULATIONS

Stack Parameters

Glass produced: 104.8 Gg/yr (115,000 T/yr)
Stack height: 38.2 m (125 ft)
Stack diameter: 1.53 m (5 ft)
Exit temperature: 353 C (650 F)
Gas flow rate: 910 m^3/min (32,000 ACFM)
Exit velocity: 8.35 m/sec (27.2 ft/sec)

Meteorological Conditions

Wind speed: at 10 meters -- 4.1 m/sec(a) (9.2 mph)
at top of stack -- 8.2 m/sec(b) (18.4 mph)

Ambient temperature at top of stack: 15 C (59 F)
Atmospheric pressure: 1000 millibars
Atmospheric stability: D(c)

Calculated Parameters

Plume rise: 5.72 m(d) (18.7 ft)
Effective stack height: 43.9 m (144 ft)

Estimated Parameter

Mean wind speed affecting the plume between the effective stack height and the surface: 6 m/sec

Emissions (G)

NO_x: 11.25 g/sec (390 T/yr)
SO_x: 6.14 g/sec (213 T/yr)
Particulates: 2.73 g/sec (94 T/yr)
CO: 0.2 g/sec (6.9 T/yr)
Hydrocarbons: 0.2 g/sec (6.9 T/yr)

(a) Average of annual mean wind speeds measured at city airports near 30 glass-container plant locations.

(b) Increase of wind with height in suburbs and level country as given in Figure 1-3 of ASME *Recommended Guide for the Prediction of the Dispersion of Airborne Effluents*, 1968.

(c) D stability is the predominant stability as determined from a cross section of Star Program results (see Table 12).

(d) Plume rise was calculated from the Holland equation for neutral stability.

be obtained for substitution into an equation or from a nomograph. The equation is

$$X_{max} = \frac{2Q}{e\pi\bar{u}H^2} \frac{\sigma_z}{\sigma_y}$$

where

X_{max} = maximum concentration (gm/m^3)

Q = pollutant emission rate (gm/sec)

$\bar{u}$ = mean wind speed (m/sec) at the height of the stack

H = effective stack height (m), the physical height of the stack plus the plume rise

σ_z = vertical plume standard deviation (m)

σ_y = horizontal plume standard deviation (m)

e = base of natural logarithms, 2.718

π = 3.14.

For D stability, the ratio $\frac{\sigma_z}{\sigma_y}$ is on the order of 0.5 varying from 0.57 to 0.24 between 0.1 km and 10 km downwind from a source(27). The ratio is approximately 1.0 for C stability. The maximum concentration occurs at a distance where $\sigma_z = h/\sqrt{2}$. Turner(27) has presented a monograph from which $x_{max}\,\bar{u}/Q$ and the distance to the point of maximum concentration can be determined for any stability and effective stack height. When emission rate and wind speed are known, the value of X_{max} can be calculated.

The environmental effect criteria are developed for 24-hr average concentrations, while the dispersion predictions discussed above are for short periods (3 to 10 min). For longer periods, one must consider that variations in wind direction and wind speed would cause the average concentration at a downwind monitor to be less than the concentration calculated for a short-term wind blowing constantly from the source to the monitor. Turner has given an equation by which the long-term average concentration can be estimated when the short-term concentration is known:

$$X_\ell = X_s \left(\frac{t_s}{t_\ell}\right)^b$$

where

X_ℓ = concentration for the long period (t_ℓ)
X_s = concentration for the short period (t_s)

The value of the dimensionless exponent, b, is between 0.17 and 0.2

t_ℓ = long-time period, min
t_s = short-time period, min.

While this equation is most applicable for X_ℓ = 2 hr or less, it can be applied to a 24-hr period. Turner gives the conversion coefficient of 0.35 for transforming a 3-min average into a 24-hr average. Other conversion coefficients are 1 hr, 0.61, and 3-hr, 0.51.

Before calculating ambient pollutant concentrations, representative meteorological parameters for the area need to be chosen. These parameters are required for determining plume rise and dispersion.

Plume rise was calculated from the Holland equation

$$\Delta H = \frac{v_s d}{u} \left(1.5 + 2.68 \times 10^{-3}\ p\ \frac{T_s - T_a}{T_s}\ d\right)$$

where

ΔH = rise of the plume above the stack, m
v_s = stack gas exit velocity, m/sec
d = inside diameter of stack, m
u = wind speed at top of stack, m/sec
p = atmospheric pressure, millibars
T_s = stack gas temperature, K
T_a = air temperature, K.

Choices of the meteorological parameters were made after a review of climatology in some of the areas of the country where glass plants are found.(29) Account was also taken of the variations of meteorology between the surface and the top of the furnace stack. The values selected for the melting furnace calculations are listed in Table 11. Stability Type D (neutral class) is the most frequently occurring stability throughout the United States as calculated by the Turner method(27) which considers the surface wind speed and the net radiation (Table 12). A surface wind speed of 4.1 m/sec was chosen as representative of the conditions at the glass plants based on a survey of the average annual wind speeds listed for the National Weather Service meteorological stations(28) located at 30 cities which have container glass plants. It should be noted that 4 meter/sec wind speeds in Turner's scheme for determining stabilities can accompany stabilities varying from Type B to Type E, depending on the solar radiation. Type D was chosen for the dispersion calculations on the basis of its predominant frequency.

Wind speeds increase with altitude and this effect was taken into account for the 38.2 meter effective mean furnace stack height for the representative plant. Wind speed in the layer in which the downward dispersion of the plume would take place, 0-44 meters, was estimated to be 6 meters/sec. This was an extrapolation from the standard wind-measurement height of 10 meters following a guide(29) giving examples of the variation of wind with height over suburban and level county areas. For stack heights of 30 to 40 meters, the wind speed is expected to be 1.5 (level terrain) to 3 (urban areas) times stronger at the top of the stack than at 10 meters.

Table 13 (in its second column) presents the maximum pollutant concentration predicted for ground level in the vicinity of the representative glass melting plant. These concentrations are the contributions from only the melting furnaces, and do not take into account other glass plant emissions or emissions from sources other than the glass plant. Table 13 also presents data for selenium, a minor pollutant emitted by a container glass furnace.

Emissions from three other sources representative of air emissions from a container glass manufacturing operations were also considered in relation to their effect on ambient-air quality. These were:

(a) Particulates from a baghouse collecting the emissions from materials handling

(b) Hydrocarbons from a container-decorating operation.

(c) Tin oxide and hydrated tin chloride particulates

(d) HCl from a surface treatment operation.

To make the ambient-concentration estimates for these sources, emissions and stack parameters were adapted from data given in the NEDS listing. Meterological

TABLE 12. RELATIVE FREQUENCY OF ATMOSPHERIC STABILITIES

	Stability Class				
Station	A	B	C	D	E and F
Milwaukee	0.001	0.031	0.094	0.636	0.238
St. Louis	0.005	0.047	0.103	0.555	0.289
Peoria	0.003	0.042	0.102	0.577	0.276
Pittsburgh	0.001	0.022	0.083	0.567	0.306
Columbus, Oh.	0.010	0.058	0.100	0.500	0.331
Mobile	0.008	0.052	0.115	0.453	0.371
Los Angeles	0.001	0.041	0.148	0.482	0.329
Dallas	0.004	0.042	0.107	0.586	0.262

* Based on Output from U.S. Department of Commerce National Climatic Center Star Program for Five Years of Data.

TABLE 13. MAXIMUM POLLUTANT CONCENTRATIONS AND SOURCE SEVERITY FOR EMISSIONS FROM THE MELTING FURNACES FOR A REPRESENTATIVE GLASS CONTAINER PLANT

Pollutant	Quality Standard ($\mu g/m^3$)	3-Minute X_{max}, ($\mu g/m^3$)	Adjusted X_{max}, ($\mu g/m^3$)	Severity, S
NO_x	100(a)	105.1	37.9(f)	0.38
SO_x	365(b)	57.0	20.5(f)	0.056
Particulates	260(b)	25.5	9.2(f)	0.035
CO	40,000(c)	1.87	0.79(f)	2.0×10^{-5}
Hydrocarbons	160(d)	1.87	0.95	5.9×10^{-3}
Selenium	200(e)	0.063	0.023(g)	3.4×10^{-2}

(a) Annual arithmetic mean assumed here as 24-hr standard for NO_2.

(b) 24-hr standard.

(c) 8-hr standard.

(d) 3-hr standard.

(e) Threshold Limit Value for 8 hrs.

(f) 3-min X_{max} adjusted to match sampling time of the standard using

$$X_{max} = X_{max\text{-}3min} \left(\frac{t_{3\ min}}{t_{std}}\right)^{0.17} .$$

(g) 3-min X_{max} adjusted to 24-hr sampling time.

conditions similar to those used in the glass-furnace emission-dispersion calculations were used for these other sources with adjustments for differing stack heights. Information regarding two of these calculations is given in Table 14. The maximum amounts of coating used for surface treating as listed in the NEDS is 6 tons. Calculation of tin and HCl emissions from the indicated values are on the order of 50 μg/sec which are considered to be negligible.

For each of the maximum ambient concentrations that were calculated, a source severity, S, was also determined. Source severity for criteria pollutants (particulates, sulfur oxides, nitrogen oxides, carbon monoxide, and hydrocarbons) is determined from the following equation:

$$S = \frac{X_{max}}{AAQS}$$

where

X_{max} = maximum average ground-level concentration of the pollutant for the time period of the standard ($\mu g/m^3$)
AAQS = ambient air-quality std ($\mu g/m^3$).

For noncriteria pollutants, the source-severity equation uses the threshold limit value instead of the ambient air-quality standard with a correction for a 24-hour period and a safety factor:

$$S = \frac{X_{max}}{TLV\ (8/24)\ (1/100)}$$

where

TLV = Threshold Limit Values for each species
8/24 = correcting factor for the 8-hr work day which is the basis for the TLV
1/100 = safety factor.

A review of the source-severity factors in Tables 13 and 14 shows the highest value to be that produced by nitrogen oxides emitted from the melting furnace stacks. For the conditions used to portray a representative

TABLE 14. MAXIMUM AVERAGE GROUND-LEVEL CONCENTRATIONS (X_{max}) OF AIR POLLUTANTS FROM CONTAINER GLASS-PLANT SOURCES BESIDES THE MELTING FURNACE

Source 1. Baghouse Controlling Materials-Handling Emissions

Emissions: 0.004 grams/sec (0.1 tons/yr) of particulates*

Emission Point -- Stack
height - 35 m; diameter = 0.3 m;
exit temperature = 10 C; exit velocity = 17.3 m/s

Species	X_{max} (3 min), μg/m^3	X_{max}, μg/m^3, (specified time)	Ambient Std	Severity Factor
Particulates	0.06	0.02 (24 hr)	260 μg/m^3	9.2×10^{-5}

Source 2. Container Decorating

Emissions: 0.44 grams/sec (15 tons/yr) of hydrocarbons

Emission Point -- Stack
height - 12.2 m; diameter = 0.6 m;
exit temperature = 149 C; exit velocity = 11.4 m/s

Species	X_{max} (3 min) μg/m^3	X_{max}, μg/m^3 (specified time)	Ambient Std	Severity Factor
Hydrocarbons	47	23 (3 hr)	160 μg/m^3	0.15

---

* Estimated as worst case situation based upon limited data from NEDS(14) (See Appendix B).

glass container plant, the source severity factor is 0.38, a low value. All other severity factors, including those from sources other than the melting furnace are also quite low.

Affected Population

As a consequence of the dispersion of pollutants, the severity starts at zero near the stack, increases downwind, reaches a maximum, and then decreases to zero again (see Figure 13). The affected population is defined as the population around a representative plant exposed to a severity greater than 1.0. To determine the downwind distances enclosing the affected population, the standard dispersion equation for the centerline concentration from an elevated source is used.

$$X = \frac{Q}{\pi\sigma_y\sigma_z u} \exp\left[-1/2\left(\frac{H}{\sigma_z}\right)^2\right]$$

where

X = pollutant concentration at surface (gm^{-3})

u = average wind speed through the dispersion layer ($m\ sec^{-1}$)

Other parameters are the same as in the earlier dispersion equation.

It is assumed that winds from all directions are equally likely. By rearranging, this equation becomes

$$\frac{X\pi u}{Q} = \frac{1}{\sigma_y\sigma_z} \exp -\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\Big] .$$

The value of X is specified by the requirement for S = 1.0 and then it is corrected to the three-minute average concentration which the dispersion equation gives. Substituting values of σ_y and σ_z from Turner's graphs of dispersion coefficient as a function of distance downwind into the right-hand

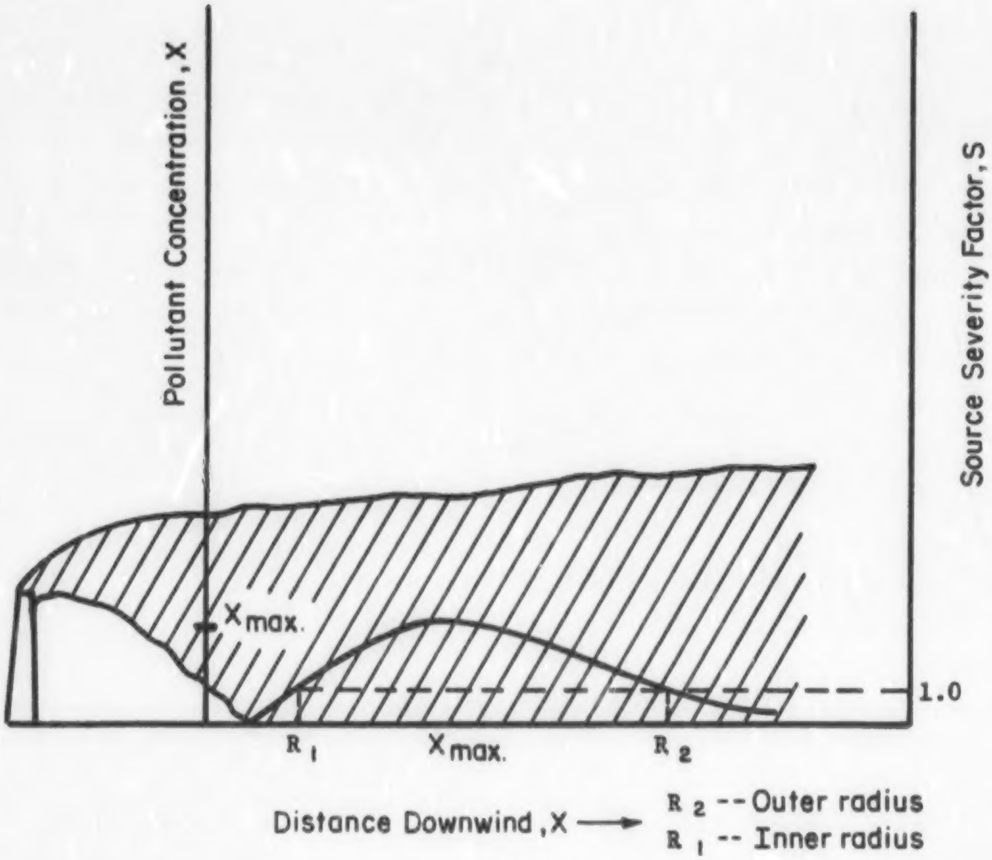
Pollutant Concentration, X
Source Severity Factor, S
X max.
1.0
R 1
X max.
R 2
Distance Downwind, X
R 2 -- Outer radius
R 1 -- Inner radius

FIGURE 13. ILLUSTRATION DEPICTING CALCULATION OF AREA WHICH CONTAINS THE AFFECTED POPULATION

side of the equation will produce a short table for values of the right-hand side of the equation versus downwind distance. These are plotted in a fashion similar to Figure 13 and the values of R_1 and R_2 are determined. These values form the inner and outer radii of an annulus enclosing the affected population.

In calculating the number of people affected, it has been assumed that the population density around the representative glass plant is 248 people per square kilometer.

Since none of the pollutant sources produced severity factors greater than 1.0, all affected population values for the container glass sources are zero.

As an illustration calculations were made for nitrogen oxides from the melting furnace using a severity factor of 0.1 instead of the standard 1.0. Results of this calculation is presented below.

	Concentration (3 min)		Affected Population*		
			Radii		
Source/Emission	Value, $\mu g/m^3$	Downwind Distance, m	Inner, m	Outer, m	Persons Affected
Melting Furnace/NO_x	105	880	420	3900	11,700

* Based on the more restrictive source severity factor of 0.1 instead of the accepted 1.0. There were no glass container sources which produced a source severity factor greater than 0.4.

SECTION V

CONTROL TECHNOLOGY

Control of emissions in the glass-container industry varies considerably, depending on the type, source, and amount. Control technology has evolved for both economic and environmental reasons. Various methods are utilized to reduce air emissions from the different portions of the glass-manufacturing process. These include: (a) development of process modifications, (b) new furnace designs, and (c) application of control equipment. For example

(1) Arsenic is no longer used as a fining agent

(2) Many fossil fuel-fired furnaces are equipped with electric boosting which can increase output, thus reducing the amount of effluent per unit of output

(3) Fabric filters, electrostatic precipitators, and scrubbers are being used or have been examined for removing dust particulates. In addition, several commercial equipment manufacturers are attempting to develop methods for removal of SO_x and NO_x emissions at the same time particulates are removed.

This section discusses the control technology currently being used or that which might be considered for use by the glass-container industry. It was not the intent of the study to consider the economics associated with the control technology or even to verify the technology itself. Rather, the purpose of this section is to identify control technology reportedly applicable to the control of emissions from glass manufacturing plants. The discussion is organized in a manner similar to the emission section.

Raw-Materials Preparation

The handling and mixing of raw materials is a source of particulate emissions from a container glass plant. Raw materials are usually conveyed from hopper railroad cars or trucks (by screw conveyors, belt conveyors, bucket elevators, or pneumatic conveyors) to elevated storage bins, as was shown previously in Figure 5. A few minor glass-batch ingredients are delivered to the plant in paper bags or cardboard drums. These are later transferred by hand to smaller storage bins or fed directly from the storage device.

Materials are gravity fed from the storage bins into weigh hoppers and then transported by transverse belts or bucket elevators into a mixer. Cullet is crushed to a desired size. After mixing, the glass batch is transferred to a charging bin located next to the glass-melting furnace or into a batch storage bin, depending upon the design of the batch-handling system. Positive displacement or vibratory feeders at the bottom of the bins feed the materials to the chargers, where it is fed into the glass-melting furnace. Cullet may be added to the batch in the mixer, while the batch is being transferred, or charged separately to the melting furnace(8).

Emissions

Little information is available regarding plant emissions due to dusting during the raw-materials handling stages of the process. As discussed in the previous section, the fraction of the dust generated which leaves the plant site will consist of particles smaller than 100 microns in diameter.

As described in the previous section on emissions, the particulate emission rate for raw-materials handling is estimated to be 22 mg/kg. Based upon the total glass batch handled by the container industry, particulates exhausted annually would average 348 Mg.

Information on the composition of these particulate emissions is not available, but they will consist essentially of the same raw materials being handled (soda ash, silica, limestone, etc.), since no chemical reactions occur during this portion of the manufacturing process. Limestone and soda ash can be expected to predominate because of their relative softness. Glass manufacturers generally specify raw materials which are coarser than 100 micron, as shown in Table 15. Consequently, the amount of raw material emitted from the plant site due to inertial forces alone would be relatively small. This is in line with the reported measurements(14).

Raw-Materials-Control Technology

Process Modifications or Material Selection. Container glass manufacturers have minimized dusting problems in batch-handling operations by limiting the amount of fine particles (<100 microns) in the batch material, as can be seen in Table 15. Specifications for glass-grade raw materials will generally require removal of the finer sizes of material, especially with softer materials that crushed to dust easier than sand.

Another batch-preparation method that is used to control dusting during handling is the addition of water to the raw batch (batch wetting). Trials have also been conducted where the batch is wet with a liquid caustic-soda solution that is substituted for soda ash(32). Water is presently added in amounts up to 4 percent to the mixed batch materials. The substitution of a caustic-soda solution for a soda ash is not generally practiced by the glass-container industry(32-33).

Efficiency of Control Equipment. Transport of raw materials in railroad hopper cars and hopper-bottom trucks (dump trucks) is still practiced. During unloading of these trucks or railroad cars, materials dumped onto conveyor belts can result in some dust being dispersed into the air. Generally, the hopper cars or trucks are connected to sealed receiving hoppers with fabric sleeves and the dust generated during the unloading operation is filtered through the sleeves or exhausted through a baghouse(34-35).

TABLE 15. GLASS-GRADE PARTICLE-SIZE SPECIFICATIONS FOR SAND, LIMESTONE, AND 10- AND 20-MESH DOLOMITE

Approximate Particle Size	U.S. Standard Mesh Size	Glass-Grade Sand, %	Glass-Grade Limestone, %	Glass-Grade Dolomite, %	
				10-Mesh	20-Mesh
2.3 mm	Cum retained on 8	-	0.0	0.0	0.0
1.3 mm	Cum retained on 16	-	2.0 max	15.0 max	-
820 µ	Cum retained on 20	0.0	10.0 max	-	2.0 max
410 µ	Cum retained on 40	12.0 max	-	-	-
150 µ	Cum retained on 100	-	-	90.0 min	80.0 min
105 µ	Cum retained on 140	92.0 min	85.0 min	-	95.0 min
74 µ	Cum retained on 200	99.5 min	94.0 min	97.0 min	96.0 min
44 µ	Cum retained on 325	100.0 min	-	-	-

Enclosing the loading area with a suitable fabric structure and sealing all covers and access openings with gaskets is effective in reducing dust during this operation. This results in an inward-air velocity across the open mouth of the bag that prevents an eruption of dust into the atmosphere(35). Trapped air and fine dust can then be filtered by a conventional fabric filter and the cleaned air exhausted into the atmosphere.

Weigh hoppers and mixers require ventilation because of surges in material from the large air flows. In older mixers, polyvinylchloride seals are installed between the rotating body of the mixer and its frame to reduce air leaks. In newer mixers, the body does not rotate. The exhaust gases are usually filtered of particulates greater than submicron size by the use of fabric filters.

The use of fabric filters for separation of particulates from air has been practiced for a number of years in the glass industry. The earliest fabric filters were known as "baghouses", since these were large free-standing units for exposed fiber bags. By passing the exhaust air through layers of a woven fabric, the particulates were collected. Unfortunately, as the thickness of the collected layer of particulates increased, the pressure differential required for continued air flow also increased. Thus, the collected dust must be periodically removed by manual or mechanical shaking. Almost all container glass plants use fabric filters to remove entrained dust particles(5,14). The fabric filters used today are totally enclosed, and most have a continuous removal operation for the trapped particulates.

The traditional woven and synthetic fabrics are used. Today, fabric filters are generally made of low-temeprature materials such as Nomex, nylon, terylene, or Orlon(34-35).

Fabric filters are used to collect particulates from the raw-materials and handling operations for several reasons. First, they have an efficiency of greater than 99 percent and they can be used to collect submicron-size particulates. In addition,the trapped particulates can later be recovered for reuse or recycle(9,34-35). One manufacturer had from 2 to 6 baghouses with a stack height less than 50 feet at a plant manufacturing 72.6 Gg (80,000 ton) of container glass per year(5,14). These used nylon-fabric filters operating at 98 percent efficiency and collecting about 72.6 Mg (80 ton) of dust per year.

Glass-Melting Operation

In a glass-melting furnace, raw materials are heated until a homogeneous viscous liquid, free of gas inclusions, is formed. Temperatures in the melter will generally fall in the 1500 to 1600 C range (2730 to 2912 F)(36). Natural gas and fuel oil are the principle types of fuel, with natural gas predominating (∿70 percent)(15,37). Over 90 percent of glass-melting furnaces have regenerative-firing systems for purposes of heat recovery and fuel conservation(14).

In order to increase melting capacity, many furnaces now have electric-boosting systems. These systems consist of several water-cooled electrodes equally spaced along the sides or bottom of the melter, below the surface of the glass. Additionally, all-electric melting is used by a few manufacturers.

Emissions

Important air emissions from a glass-melting furnace consist of NO_x, SO_x, and particulates. Other emissions can include CO, hydrocarbons, and selenium.

Nitrogen oxides represent the largest fraction by mass, about 54 percent of glass-furnace emissions(14,18,38).

As was described earlier, the source test measurements of NO_x emission rates vary from 0.58 to 6.29 g/kg of glass produced. For additional information, see Appendix B. Based on an average emission rate of 3.07 g/kg, glass-melting furnaces with a total production rate of 12.656 Tg would emit 38.8 Gg of NO_x yearly(14).

SO_x, on the other hand, depends both on the sulfur content of the fuel and on the sulfur content of the batch material. Sulfur present in the fuel oil will oxidize and appear as SO_x in the exhaust gas. A fuel oil containing 1 percent sulfur by weight emits ≈ 600 ppm SO_2 in the flue gas(21). Sulfur is also present in the batch materials, usually as Na_2SO_4. During heatup, the sulfate decomposes and sulfur dioxide is formed, some of which is chemically encorporated into the glass (as SO_3^-) and some released within the furnace. An average emission rate of SO_x is 1.70 g/kg. Thus, plants producing 12.656 Tg of glass annually would emit approximately 21.5 Gg of SO_x yearly.

Particulate emissions from a glass-melting furnace result primarily from volatilization of materials in the melt that combine with gases such as SO_3 to form condensates in the flue system. Particulate emissions from a glass-container furnace consist of approximately 80 percent sodium sulfate(9,18,22-24). These particulates form from the condensed vapors in the melt and are submicron sized(10,22-24). The median particle diameter from a flint glass furnace was found to be 0.13 μ(24-25).

Source-test measurements for particulate emission rates vary from 0.13 to 1.95 g/kg of glass produced. This averages to a particulate emission rate of 0.68 g/kg.

Other emissions exhausted from glass-melting furnaces include CO, hydrocarbons, and selenium.

Carbon monoxide is probably exhausted from the glass-melting furnace as a result of incomplete fuel combustion. Source-test measurements have reported emission rates from 0.05 to 0.13 g/kg. An estimated average emission rate is 0.07 g/kg.

Hydrocarbons are also formed in the glass-melting furnace as a result of incomplete fuel combustion. Source-test measurements have reported emission rates from 0.01 to 0.53 g/kg. The calculated average emission rate was 0.08 g/kg. Actual emission rates are a function of firing conditions (extent of fuel/air mixing, excess air, firing temperature).

Selenium is generally used in amounts of 0.001 weight percent or less in the batch as a decolorizer to neutralize the green tint in container glasses caused by iron impurities.(9,10,22) No test measurements on actual selenium emissions have been reported, but it likely leaves the stack as selenium vapor, because of its low vaporization temperature (315 C for SeO and 685 C for Se)(9,22). A worst case emission rate was calculated to be 0.002 g/kg, with total annual emissions of 0.02 Gg.

Glass-Melting-Control Technology

Control of emissions from the glass-melting furnace have occurred primarily because of environmental considerations. Four general approaches have been employed:

(1) Modification of feed material
(2) Modification of furnace design
(3) Increase of checker volume
(4) Adoption of commercial-control apparatus.

Modification of feed material and furnace design have been primarily used to control gaseous emissions, while the other two methods are used for control of particulate emissions.

Modification of Feed Material. Raw materials have a tendency to vaporize or decompose in the glass-melting furnace. Several raw materials that readily vaporize include nitrates and selenium. By minimizing the amount of these or other ingredients used or by substitutions of materials, the amount of gaseous emissions exhausted from the glass-melting furnace is reduced. For example, arsenic has been essentially eliminated as a fining agent. Cerium is used to partially replace selenium as a decolorizer. In addition to reducing the selenium in the batch (by about 40 percent), this modification leads to the elimination of arsenic in the batch, since cerium and arsenic are not compatible. Cerium is especially appealing because it tends to form high-melting compounds which do not readily vaporize.

Modification of Furnace Design. Increasing the fuel efficiency of the glass-melting furnace can in turn lead to a decrease in combustion products, a decrease in dust entrainment by hot combustion gases passing over the melting glass batch, and possibly a decrease in furnace temperature. In addition, emissions from low melting and easily vaporized fluxing or fining agents can be lowered. Several methods currently in practice to improve furnace efficiency are:

(1) Better instrumentation for regulating air/fuel mixtures and monitoring furnace temperature and stack gas composition.

(2) Combustion control to produce long luminous flames that eliminate spurious hot spots in the furnace and provide better heat transfer to the melt

(3) Improved refractories to increase corrosion resistance, which permits furnaces to be more fully insulated

(4) Use of electric melting to reduce incomplete combustion and volatilization losses

(5) Use of electric boosting to increase furnace capacity, increase furnace efficiency, and lower temperatures above the molten glass.

All of these methods have been employed to control gaseous emissions. Sulfur oxides that form can be controlled by both limiting the sulphate in the feed material and by the improvement of furnace efficiency. Ryder and McMackin(18) found that the SO_x emission rate increased directly with an increase in production rate on a sideport furnace melting soda/lime glass. This increase comes about because of the larger quantities of sulphate being added to the furnace when the production rate doubled.

NO_x emissions can be also lowered when the furnace efficiency is increased if the furnace temperature also drops. A 10 percent decrease in fuel consumption will result in a 10 percent decrease in NO_x emissions(39-40).

Electric boosting is commonly used on fossil-fuel fired furnaces in the container glass industry, primarily to increase output. About 40 percent of these glass-melting furnaces are equipped with boosters. Boosting will normally result in a reduction in emissions per unit of output.(15)

Electric melting furnaces essentially eliminate both particulate and gaseous emissions from the glass-melting operation. In 1975, less than 3 percent of container glass manufacturers used electric melting(15).

Adoption of Commercial-Control Apparatus. Particulates can be cleaned from the glass furnace exhaust by scrubbers, fabric filters, or electrostatic precipitators (ESP). Figure 14 shows a breakdown of commercial-control apparatus presently in use. Scrubbers can also be used to collect SO_x emissions, while fabric filters and ESP's only remove particulates. Teller(51) suggested spraying the stack gas with an alkaline solution. This would cause the acidic gases (SO_x, HF, or HCL) to react and form particulates that could then be collected by the control device.

Scrubbers. One type of particulate scrubbing is a two-step process. Initially, particles in the exhaust gases are "contacted" or wet by a scrubbing fluid that draws the particles into agglomerates. These agglomerates are then separated from the gas stream by an inertial mist-elimination process.

A low-pressure (<10-in. water) centrifugal scrubber used by one glass company in California(9) had two separate contacting sections within a single casing. Separate 50.7 metric horsepower (50 horsepower) circulating fans forced dirty gas through each section containing two to three impingement elements similar to fixed blades of a turbine.

One reference(41) mentions a scrubber that uses a packed-bed preconditioning chamber. Hot gases (538 C) containing volatilized sodium compounds enter the chamber, and the vapors condense out onto the packing material. This material is wet by a scrubbing solution and provides a large surface area for condensation. A standard Venturi-type scrubber completes the system. This scrubber is presently installed on a 0.181 Gg/day (200 ton/day) container glass furnace and it reduced particulate loading from more than 0.23 to less than 0.046 g/sdm^3 (from more than 0.10 to less than 0.02 g/sdcf)(41).

One flint-glass manufacturer(13) installed a tower scrubber (2.9-meter diameter) on a 44.8 $meter^2$ (482 ft^2) melter. Hot effluent from the furnace is initially quenched and saturated with a caustic solution passing through the exhaust gas at 900 gal/min. The gas then passes into a 300 gal/min variable throat Venturi operating at 30 in. of water. This scrubber has been plagued by malfunctions and breakdowns. A highly visible steam plume is exhausted when it is not working.

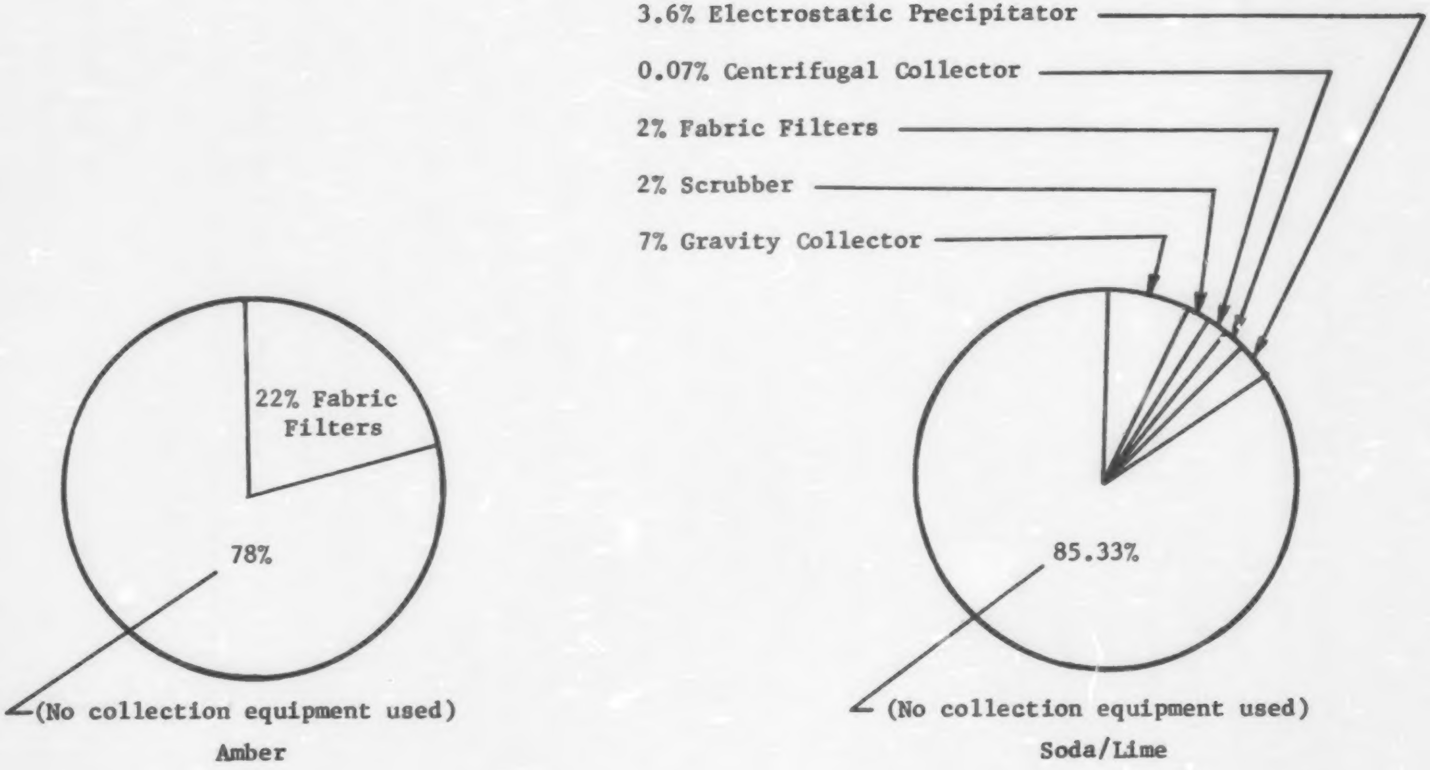

FIGURE 14. USE OF COMMERCIAL-COLLECTION EQUIPMENT FOR EMISSION CONTROL ON BOTH AMBER AND SODA/LIME GLASS FURNACES(14)

Fabric Filters. Fabric filters, also known as "baghouses"(36), collect particulates by filtering exhaust gas from container glass-melting furnaces through closely woven natural or synthetic fabric filters that are capable of trapping submicron particulates. Unlike wet scrubbers, fabric filters are unaffected by variations in the gas flow rate. Temperature control, however, is critical for proper functioning and the type of fabric filter selected is dependent upon the temperature of the gases exhausted. Fabric filters are generally made of cotton sateen, standard nylon, wool, dacron, orlon, NOMEX, teflon, and fiberglass(35-36). Maximum operating temperatures for these fabrics are given in Table 16.

TABLE 16. MAXIMUM USE TEMPERATURE FOR VARIOUS FABRIC-FILTER MATERIALS

Fabric	Maximum Temperature, C
Cotton Sateen	99
Standard Nylon	93
Wool	107
Dacron	135
Orlon	135
Nomex	204
Teflon	232
Fiber Glass	288

Since stack gas from a glass container melting furnace is at 316 to 645 C (600 to 1200 F)(42), the gas must be cooled to a temperature compatible with the fabric filter bag. This can be accomplished by using the following methods, either alone or in combination with each other

(1) Air dilution

(2) Radiation-cooling columns

(3) Air/gas heat exchangers

(4) Water-spray chambers.

Dilution of off gases with air is the simplest and most trouble-free method of reducing temperature, but requires the largest baghouse because of the increased volume of gases. Air-to-gas heat exchangers, and radiation and convection ductwork are subject to fouling from dust in the effluent. A water-spray increases humidity and requires careful temperature control to avoid condensation, but does permit use of smaller baghouses. Care must be taken, with all of these methods, to avoid cooling the gas to the temperature where SO_3 and H_2O would condense out and foul or react with the fabric filters.

In addition to being selected for their thermal compatibility, fabricfilter bags must also be corrosion and abrasion resistant. Cotton, orlon, and dacron can deteriorate from the SO_3 in the flue gas(26).

A fabric-filter air-pollution-control system was installed in 1974 on a 41.8 m^2 (450 ft^2) melter producing amber glass(13). The 482 C (900 F) effluent from the furnace was initially cooled to 177 C (350 F). A fine powder aluminate precoat was then introduced into the air stream at 18.1 kg/hr (40 lb/hr) along with ambient air. This further reduced the gas temperature to 121 C (250 F). The baghouse contained 1200 m^2 (12,915 ft^2) of dacron-filter cloth divided into six compartments, each containing 900 filter bags. During normal operation, the air-to-cloth ratio was 1.55, but this would increase to 1.86 during the cleaning cycle. The pressure drop ranged from 3.5 to 4.5 in. of water across the bags. An exhaust blower had to develop 16 to 18 in. of water pressure to overcome the resistance of the checkers, heat exchanger, baghouse, and about 46 meters of duct. Initially, the heat exchanger required maintenance about 15 percent of the time due to plugging with material condensing from the gas stream. By blocking off about 40 percent of the tubes, the temperature increased slightly, but this permitted a normal maintenance schedule. Discharge of particulates from the baghouse outlet was typically 1.1 kg/hr (2-3 lb/hr). Tests using a Brinks Impactor showed these particulates to be <0.75 micron.

Electrostatic Precipitator (ESP). In an electrostatic precipitator (ESP), a voltage source creates a negatively charged area, usually by hanging wires in the gas flow path. Grounded collecting plates composed the sides of the ESP. A powerful electric field is created by the high potential difference between these grounding plates and the discharging wires. As the gas stream passes through the field, the particles become electrically charged and are drawn to the collecting plates. Periodically, accumulated particles are removed from these plates by vibration, rapping, or rinsing. Thus, by applying the collecting force only to the particles to be collected, a much lower power input is required (i.e., 200 watts per 0.5 m^2/s)(33).

NAFCO Engineering, Ltd. (a Japanese firm) has developed a new type of ESP. In contrast to the conventional units, the NAFCO ESP uses thousands of stainless steel needles affixed to the leading and trailing edges of positively charged electrode plates. Thirty five of these systems are now in operation in Japan, with nine of them being used on soda/lime glass-melting furnaces(25).

United McGill Corporation, who is the licensed U.S. distributor for the NAFCO ESP, has installed the unit on 10 soda-lime glass furnaces to date(25). All of these systems are designed to have an outlet loading of <0.046 g/std m^3 (0.02 g/scfd).

An 84.4 m^2 (908 ft^2) melting furance, used for producing flint glass, had an ESP installed in early 1974(13). It consisted of dual chambers, where the air flow could be directed to either chamber or divided between them. Each chamber had three electrical fields connected in series. Designed for 12.9-sec treatment time at 0.67 m/s (2.2 fps) velocity through the treater, one chamber was found to be as effective as two, the conclusion being that the system was overdesigned.

Technological Advances. Collector systems previously discussed are primarily useful for collecting particulates and for decreasing opacity of gaseous emissions. One company now offers dry and wet systems(51) to control both particulate and gaseous emissions. A nucleation scrubber is used on their wet system to effect collection of submicron particulates and acidic gases (HF and SO_x). A solid absorbent, on the other hand, is injected into the gas stream to react with the noxious gases in their dry system. The absorbant is then separated from the gas along with particulates in a fabric filter.

A patent (U.S. 3,789,628) was issued for a scrubber where an aqueous solution of sodium silicate is sprayed into the gases as they are exhausted in the furnace stack. Water from the solution evaporated in the gas stream and the sodium silicate forms a small sticky sphere which the patent claims to react chemically with NO_x and SO_x, and physically with particulates. These spheres can then be collected and recycled into the glass batch(43).

The quantity of NO_x from a glass-melting tank was studied by Kitayama, et al(6), in order to evaluate methods for reducing fuel consumption under photochemical smog warnings. A glass-melting furnace (of unknown glass composition) with a 154.2 Gg/day (170 ton/day) capacity using preheated air at 1100 C, emits 850-1000 ppm of NO_x. By varying the damper opening and reducing the excess air by 10 percent, the NO_x emissions were reduced to 480 ppm. When the excess air was reduced 20 percent, the NO_x emissions were reduced to 45 ppm.

Takasaki(44) reports on a method for removing NO_x from flue gases by wet oxidation and absorption. This technique claims to eliminate more than 90 percent of the NO_x from the flue gas of a glass-melting furnace. By using activated carbon and chlorine acid soda, a pilot plant with 51 kg m^3/hr reduced its NO_x emissions by 95 percent. This system consists of a special liquid-gas contact tower that utilizes a chlorine dioxide and chlorine oxidizing agent. NO is converted into NO_2, which is absorbed by the liquid and stabilized. The existing gas contains no NO, <10 ppm NO_2, <5 ppm SO_2, no chlorine oxide, chlorine, or hydrogen chloride, 13 percent CO_2, 3.5 percent O_2, and 0.29 mg/kg m^2 of dusts. Other details were not reported.

Kanenatsu(45) reports on scrubbers handling 377, 7.1, and 28.6 kg m^3/hr m/hr of SO_x in the flue gas. By using a wet or dry desulfurization method, the sulfur oxides are absorbed by NaOH solutions and oxidized in air, and the SO_x recovered as mirabilite.

Kanematsu(46) suggested use of low sulfur fuels, high stacks, and stack gas-desulfurization systems as methods for controlling SO_x emissions.

Efficiency of Equipment

Least effective and least expensive of the air-pollution control devices is the wet scrubber(13). In addition to having numerous malfunctions and breakdown, they have been found to exhibit particulate-collection efficiencies as low as 66 percent(13) to as high as 90 percent(33) (if grain loadings were low). By fitting the column with impingement plates, efficiency can range up to 95 percent with particles as small as 5 microns(33). A major advantage of this system is its ability to remove acidic gases.

Baghouses have a reputation for high efficiency and dependability. Fabric filters are capable of >99 percent efficiencies and can collect particulates down to below 0.75 micron(13,33). Major disadvantages are that exhaust gases must be pretreated to remove gaseous emissions and must be cooled before they contact the low-temperature fabrics.

Electrostatic-precipitator performance is highly sensitive to temperature and volume fluctuations. Electrical characteristics of particulates, which affect collection efficiency, vary with temperature, humidity, SO_2 content, and the type of particulate. Conventional ESP's have been shown to have efficiencies up to 95 percent and collect particulates down to submicron size. The NAPCO ESP, on the other hand, has a reported outlet loading of less than 0.046 g/std m^3 (0.02 grains/scf)(25). For an uncontrolled emission rate of 1 kg of particulate/Gg (2 lb of particulate/ton) of glass and an air flow of 3119 std m^3/Gg (100,000 scf/ton), the efficiency is reported to be 85 percent. For an emission rate of 10 kg/Gg (20 lb/ton), the efficiency is reported to be greater than 98 percent. This ESP was designed so additional sections could be added so efficiencies greater than 99 percent could be obtained(33,47).

Wet or dry desulfurization methods, presently in use by a glass company, in Japan, has shown efficiencies of better than 97 percent for the wet and 80 to 90 percent for the dry for SO_x removal.

Forming and Finishing

As the glass leaves the forehearth of the furnace, the molten glass is cut into "gobs" by a pair of mechanical shears. Chutes direct the gobs from the feeder into blank molds where it is formed by one or two methods.

With the "blow-and-blow" technique, the gob is settled with compressed air and preformed into a parison with a counter blow. The parison is inverted and transferred into the blow mold where it is blown into its final shape.

Wide-mouth containers, on the other hand, are formed by a "press-and-blow" technique. The gob is settled by pressing with a plunger and "puffed" with a counter blow. The parison is inverted and transferred for final blow forming.

The surface of approximately 30 percent of glass containers are treated in an operation where hot bottles from the forming machine pass through a fume chamber containing v pors of tin or titanium tetrachloride. A surface layer of the metal oxide forms on the container. Unreacted hydrated metal chlorides are exhausted into the atmosphere. The containers are then annealed at 593 to 649 C (1100 to 1200 F) and uniformly cooled in gas-fired, continuous ovens called lehrs.

A polymer coating may then be applied by spraying the containers with an aqueous dispersion of coating material. The heat from the containers evaporate the water and fuze the polymer into a uniform surface coating.

Decorative coatings are applied to about 3 percent of the glass containers. Vitrifiable glass enamels or organic resins are applied by brush, stencils, banding machines, rubber stamps, offset processes, electrostatic printing, and silk screen printing. Metallic decorating materials (liquid bright metals, such as gold, platinum, palladium, and silver, which leave a mirror-like coating when fired on the glass) are also applied in the same manner. If a container is to be glazed, a water suspension of glass-forming ingredients is applied by spraying or dipping. These decorative coatings are then cured in annealing ovens at approximately 600 C.

Forming Emissions. Molds on forming machines, gob shears, and delivery chutes are lubricated with solutions ranging from grease and oils to graphite and silicone-based emulsions. During the past decade, silicone emulsions and water-soluble oils have replaced grease and oil lubricants on gob shears and gob delivery systems(9). Grease and oils are still used on molds and causes white smoke emissions during flash vaporization of the swab. Although the smoke dissipates in a few seconds, hydrocarbon vapors are released. These emissions are released inside the plant but probably drawn outside through the large ventilators above the melting furnace and are minor.

Forming and Finishing Control Technology

Efforts to control the hydrocarbons emissions have centered on finding lubricants capable of withstanding high temperature (900 C) and not volatilize. Use of silicone emulsions are water-soluble oils (90 to 150 parts of water to 1 part oil or silicone) can eliminate these emissions. Unfortunately, they have not performed well as mold-release compounds(9). Emissions from the forming machinery are dispersed within the plant and exhausted by the room ventilating systems. No companies were identified which used any control device for these emissions.

Surface Treatment

Emissions. Emissions from the surface treatment of glass containers with tin or titanium tetrachloride include metal oxides, hydrated metal chlorides, and HCl that are released into the atmosphere. The emission rate is estimated to be 0.02 g/kg for metal oxides, 0.03 g/kg for hydrated metal chlorides, and 0.02 g/kg for HCl.

Particulates exhausted are generally composed of submicron size metal chloride and oxide. A calculated particulate emissions rate is 0.05 g/kg.

Surface Treatment Control Technology

A U.S. Patent 3,789,109 describes(48) an apparatus to be used for cleaning solid, liquid, and gaseous pollutants from a hot-end surface treatment station of a container glass manufacturing plant. In this apparatus, the air discharging from the hood is heated until the metal chlorides in the air disassociate to metallic oxides and hydrogen chloride gas. Exhaust gases are then sprayed with fresh water to cool the stream. Water reacts with the hydrogen chloride to form hydrochloric acid. Exhaust air passes into a scrubber where the pollutants are removed , and then conveyed to a gas scrubber where metal oxides are removed.

Decorating

Emissions. Hydrocarbon emissions from organic solvents and binders used in coatings on containers are released when decorative coatings are cured in annealing lehrs. A calculated emission rate for these hydrocarbons is 4.37 g/kg. Only 3 percent of the containers are decorated, giving a total annual emission of 1.44 Gg.(2)

Deccrating-Control Technology

Process modifications are difficult to accomplish without harming the quality of the coating(49). In addition, they do not completely eliminate hydrocarbon emissions. Several such changes involve the substitution of solvents and a reduction of solvent concentration in the coating.

Hydrocarbon emissions can be controlled by incineration, absorption (activated charcoal or silica gel), or condensation(49).

SECTION VI

FUTURE GLASS-CONTAINER PRODUCTION

The future production levels for glass containers is highly unpredictable because of three major factors: (1) shortages in natural gas and substitute energy sources, (2) potential large-volume penetration of the beverage-container market by plastics plus continuing penetration by cans, and (3) possible legislation restricting or outlawing nonreturnable containers.

The shortage of natural gas and the allocation of petroleum products places a constraint on the container-glass industry. In recent years, most of the industry has used petroleum products primarily as a reserve or standby fuel and, therefore, does not have a base period of any significant usage. At the same time, the industry has incurred reductions in the use of natural gas, its primary fuel. Since oil is the only normal replacement fuel, allocations based on historical demand would indeed constrain the production on container glass in the United States.

The primary substitute fuel oil used by the glass industry is a distillate, such as No. 2 fuel oil. However, both distillates and residuals are used by the industry in the melting operation with properly designed fuel-handling and burner systems.

Oil cannot normally be substituted for natural gas in other nonmelting operations, such as in the refiner, forehearth, and annealing lehrs, for reasons of glass quality. In such areas, propane is the only substitute. If a limited amount of natural gas is available in the glass plant, it is usually reserved for use in the nonmelting areas, assuming oil is available for substitution in the melting area.

The extent to which plastic containers will penetrate the beverage market is still highly speculative. But, extensive research to resolve limiting factors such as cost, gas permeability, and creep has led to test-market introduction of plastic containers by the two largest soft-drink companies Coca-Cola Company and Pepsico, Inc. The initial plastic soft-drink containers have concentrated on the 32-oz capacity or larger sizes of which they are most cost competitive. Also, a large beer manufacturer has announced intent to package in metal and plastic in the future rather than glass(50). If energy costs continue to escalate, the competitive position of plastic containers may be improved both in manufacturing and transportation (distribution) costs.

Metal cans have been claiming an increasing percentage of the smaller capacity soft-drink containers and may be expected to increase these inroads barring any legislative effects.

Federal legislative action relative to returnable versus nonreturnable beverage containers has been under consideration for some time. If such legislation does become law, it could have a major impact on both the total numbers of glass containers manufactured and the competitive position of glass, plastics, and metal. The details of such legislation would determine how it would effect glass-container production.

The future of glass container production will also depend upon the success of the industry's research on developing very light-weight beverage containers. If gross reductions in glass weight are achieved through improved forming techniques, strengthening processes, plastic coatings, etc., then the competitive position with metal and plastic containers could lead to improved growth potential.

Historically, the shipments by the industry have grown an average of 6 percent annually since 1967, as can be seen in Table 17.

TABLE 17. GLASS CONTAINER PRODUCTION STATISTICS(2)

Year	Tg	Production, 10^6 tons	10^6 Bottles
1974	11.00	12.13	39,800
1973	11.32	12.48	39,790
1972	10.77	11.87	38,550
1967	8.39	9.25	33,271

This growth is attributable primarily to the increased popularity of the nonreturnable bottle. In recent years, the growth has been less. It is likely that 1980 production will be 20 percent higher than for 1974. Total National emission will also increase by this amount without changes in control technology.

SECTION VII

UNUSUAL RESULTS

As mentioned in the previous section, the use of natural gas is declining as a primary energy source by glass container manufacturers. Its usage has dropped from approximately 83 percent in 1971(15) to about 70 percent in 1975(2). Oil usage is increasing and this will have a direct effect on SO_x and possibly particulate air emissions. Tending to counter this effect is improved furnace efficiency achieved by process modifications that act to reduce stack emissions. It is not possible at this time to predict the quantitative impact of these changes on future air emissions.

REFERENCES

(1) Current Industrial Reports: Glass Containers Summary for 1974, Series M-32G (74)-13 (May 1975).

(2) Personal communication with Glass Containers Manufacturer Institute (GCMI).

(3) "Directory Issue", The Glass Industry, 56 (10), 1975.

(4) "Glass Factory Directory Issue", American Glass Review, 95 (8A), February 28, 1975.

(5) Private communication with anonymous manufacturer.

(6) Kitayama, Hiroshi, Hideo Hayashi, Sataro Iwasaki, Tadashi Fujimura, Tomohiko Mujano, Hideaki Murayama, Tomihiro Myuhata, "Effect of Combustion Conditions on Nitrogen Oxides Formation of Furnaces", presented at Japan,Soc. Air Pollution, 14th annual meeting, Fukushima, Japan, (Jov. 1973).

(7) Hutchins, J. R. III, and Harrington, R. V., "Glass" from the Encyclopedia of of Chemical Technology, 2nd Edition, 10, John Wiley & Sons., Inc. (1966) 533-604.

(8) Bauer, W. C., Tooley, F. V., and Manring, W. H., "Batch Materials Handling and Preparation", The Handbook of Glass Manufacture, 1, 57-94 (1974).

(9) Danielson, J. A., Air Pollution Engineering Manual, 2nd Edition, EPA Publication No. AP-40 (May 1970).

(10) Anon, "A Screening Study to Develop Background Information to Determine the Significance of Glass Manufacturing", prepared by Research Triangle Park Institute for EPA, Contract No. 68-02-0607-Task 3 (December 1972).

(11) Private communication with E. Stable, Owens-Illinois, Inc., Toledo, Ohio.

(12) Chemical and Process Tech. Encyclopedia, Ed. Considine, 551-561 (1968)

(13) Simon, Herbert and Wiliamson, E., "Control of Fine Particulates from Continuous Melting Regenerative Glass Furnaces", presented at the 68th Annual Meeting of the APCA, Boston, Massachusetts (June 15-20, 1975).

(14) Anon, National Emission Data System, Environmental Protection Agency Research Triangle Park, North Carolina (1974).

(15) Schorr, J. R. and Anderson, G. A., Final Report on Industrial Energy Study of the Glass Industry to FEA and DoC", Battelle Columbus Laboratories, Contract No. 14-01-0001-1667, pages 80-142 (1974).

(16) Lillis, E. J., and Young, D. "EPA Looks at 'Fugitive Emissions'", J. Air Pollution Control Assoc., 25 (10), 1015-18 (1975).

(17) Air Pollution, Vol. 1, Edited by A. C. Stern, 2nd Edition, Academic Press, N. Y. (1968), "Nonviable Particles in the Air', (M. Corn). 49-52.

(18) Ryder, R. J. and McMackin, J. J., "Some Factors Affecting Stack Emissions from a Glass Container Furnace", The Glass Industry, 50, 307-11, 346-350 (June 1969).

(19) Arrandale, R. S., "Air Pollution Control in Glass Melting", Symposium Sur La Fusion du Verre, Brussels (October 1968), 619-644.

(20) Anon, State-by-State Listing of Source Types that Exceed the Third Decision Criteria, Special Project Report, Monsanto Research Corp., Contract 68-02-1874, 1-3 (1975).

(21) Reed, R. J., "Combustion Pollution in the Glass Industry", The Glass Industry, 54 (4), 24-26, 36 (1973).

(22) Arrandale, R. S., "Pollution Control in Fuel Fired Tanks", The Glass Industry, 55 (12), 12ff (August & November 1974).

(23) Davis, R. E., Manring, W. H., and Bauer, W. C., "Carryover Studies in Glass Furnaces", presented at the 34th Annual Conference on Glass Problems, 109-126, U. of Ill. (November 1973).

(24) Stockham, John D., "The Composition of Glass Furnace Emissions", Journal of the Air Pollution Control Assoc., 21 (11), 713-715 (1971).

(25) Custer, W. W., "Electrostatic Cleaning of Emissions from Lead, Borosilicate, and Soda/Lime Glass Furnaces", presented at the 35th Annual Conference on Glass Proglems, Ohio State University (Nov. 14-15, 1974).

(26) Frantz, C. J., Miser, D. L., Troy, H. N., and Stabbe, E. D., collected papers from the 32nd Annual Conference on Glass Problems, Dept. of Ceramic Engineering, University of Illinois, 25-38 (1971).

(27) Turner, D. B., Workbook of Atmospheric Dispersion Estimates, EPA Publication No. AP-26 (1970), Figure 3-9.

(28) Climatic Atlas of the United States, U.S. Dept. of Commerce (1968).

(29) Recommended Guide for the Prediction of the Dispersion of Airborne Effluents, Edited by M. Smith, ASME (1968).

(30) Reznik, R. B., Source Assessment: Flat Glass Manufacturing Plants, EPA Environmental Protection Technology Series, Monsanto Research Corporation, Dayton (October 1975).

(31) Mills, H. N., and Jasinski, J., "Evaluating Batch Changes", The Glass Ind., 51 (5), 223-227 (1970).

(32) Tooley, F. V., "Raw Materials", Handbook of Glass Manufacture, Vol. 1, Books for Industry, New York (1974), Chap. 2.

(33) Rymarz, Ted M., and Lipstein, David H., "Removing Particulates from Gases", Chemical Engineering Deskbook, 82 (21), The McGraw-Hill Publishing Company, New York 113-129 (October 1975).

(34) Swift, P., "Dust Control Related to the Bulk Delivery of Particulate Materials", The Chemical Engineer, 143-150 (March 1975).

(35) Edmundson, J. N., Rietz, L., Weise, R. L., and Fraas, J., Collected papers from the 32nd Annual Conference on Glass Problems, Dept. of Ceramic Engineering, University of Illinois, 39-54 (1971).

(36) Arrandale, R. S., "Furnaces, Furnace Design, and Related Topics", Handbook of Glass Manufacture, Vol. 1, Books for Industry, New York (1974), Section 5, 249-387.

(37) Hibscher, William, Stertz, R., The U.S. Glass Industry's Challenge in These Energy Critical Times", presented at the 35th Annual Conference on Glass Problems, The Ohio State University, 85-101 (November 1974).

(38) Bartz, D. V., KVB Engineering, Inc., Control of Oxides of Nitrogen from Stationary Sources in the South Coast Air Basin of California, California State Air Resources Board (1974).

(39) Anon, "Symposium on Pollution, Stratford-Upon-Avon, 30 May-1 June 1973", Glass Technology, 1 (6), 140-144.

(40) Teller, A. J., "Control of Emissions from Glass Furnaces", Ceramic Bulletin 51, 637-640 (1972).

(41) Keller, G., "Scrubber System Lightens Load of Glass Furnace Emissions", Chemical Processing, 38, 9 (Jan. 1975).

(42) Teller, A. J., "Control of Emissions from Glass or Ceramic Manufacture", presented to ACS, St. Louis, Missouri, September 1971.

(43) Mahoney, W. P., "Method for Controlling Furnace Emissions", U.S. Pat. 3,789,628 (1974).

(44) Takasaki, Shoichi, "Flue Gas Denitration by West Oxidation and Absorption", Heat Management Pollution Control, 26 (1), 57-62 (Jan. 1974).

(45) Kanematsu, Jado, "Air Pollution Control in Glass Industry", Seramikk (Ceramics), 9 (1), 49-55 (Jan. 1974).

(46) Kanematsu, Jado, "Countermeasures for Preventing Air Pollution Caused by Glass Industry", Seramikksu (Ceramics), 9 (1), 15-21 (1974).

(47) Wright, R. W., "Application of Electrostatic Precipitators for the Control of Container Glass Emissions", IEEE Trans. on Industry Applications, 1A-11 (No. 4), 447-456 (July 1975).

(48) Lyon, R. S. and Lyon, R. L., "Method for Cleaning a Gas", U.S. Pat. 3,789,104 (1971).

(49) Troy, H. N. and Kalter, P. A.,"Pollution Control and Glass Decurating", The Glass Ind., 52 (3), 102-105 (March 1971).

(50) LeMaire, W. H., "Why Bill Coors Wants A Plastic Bottle", Packaging Engineering, January, 1976.

(51) Teller, A. J., "Control of Glass Furnace Emissions", Glass Industry, 57 (2), 15-19, 22 (February, 1976).

(52) Roos, P. W., "Lehr Priority: Design Concepts to Save Energy", The Glass Industry, 56, 18-22 (April, 1975).

(53) Hangebrauck, R. P., Von Lehmden, D. J., and Meeker, J. E., "Emissions of Polynuclear Hydrocarbons and Other Pollutants from Heat-Generation and Incineration Processes", Journal of the Air Pollution Control Association, 14, 267-278 (July, 1964).

TABLE A-1. GEOGRAPHICAL LISTING OF THE 122 CONTAINER GLASS PLANTS

State	Plant	City	County	AQCR	County Population Density, persons/km^2 (persons/mi^2)	Furnaces
Alabama	Brockway Glass Co., Inc.	Montgomery	Montgomery	2	80 (206)	3
Arkansas	Arkansas Glass Containers Corp.	Jonesboro	Craighead	20	28 (73)	3
California	Anchor Hocking Corp.	Los Angeles	Los Angeles	24	662 (1714)	3
	Anchor Hocking Corp.	San Leonadro	Alameda	30	558 (1445)	1
	Ball Corp.	El Monte	Los Angeles	24	662 (1714)	2
	Brockway Glass Co., Inc.	Oakland	Alameda	30	558 (1445)	2
	Brockway Glass Co., Inc.	Pomona	Los Angeles	24	662 (1714)	1
	Gallo Glass Co.	Modesto	Stanislaus	31	50 (127)	4
	Glass Containers Corp.	Antioch	Contra Costa	30	290 (752)	1
	Glass Containers Corp.	Hayward	Alameda	30	558 (1445)	1
	Glass Containers Corp.	Vernon	Los Angeles	24	662 (1714)	2
	Kerr Glass Mfg. Corp.	Santa Ana	Orange	24	696 (1802)	1
	Latchford Glass Co.	Los Angeles	Los Angeles	24	662 (1714)	4
	Madera Glass Co.	Madera	Madera	31	7 (19)	2
	Owens-Illinois	Los Angeles	Los Angeles	24	662 (1714)	
	Owens-Illinois	Oakland	Alameda	30	558 (1445)	
	Owens-Illinois	Tracy	San Joaquin	31	78 (201)	
	Thatcher Glass Mfg. Co.	Saugus	Los Angeles	24	662 (1714)	3
Colorado	Columbine Glass Co.	Wheat Ridge	Arapahoe	36	76 (196)	2
Connecticut	Glass Containers Corp.	Dayville	Windham	41	61 (159)	4
Florida	Anchor Hocking Corp.	Jacksonville	Duval	49	259 (670.3)	3
	Industrial Glass Co., Inc.	Bradenton	Manatee	52	49 (127)	2
	Owens-Illinois	Lakeland	Polk	52	46 (119)	
	Thatcher Glass Mfg. Co.	Tampa	Hillsborough	52	180 (467)	2

TABLE A-1. (Continued)

State	Plant	City	County	AQCR	County Population Density persons/km^2 (persons/mi^2)	Furnaces
Georgia	Glass Containers Corp.	Atlanta	Fulton	56	433 (1122)	2
	Midland Glass Co.	Warner Robin	Houston	54	63 (164)	1
	Owens-Illinois	Atlanta	Fulton	56	433 (1122)	
Illinois	Anchor Hocking Corp.	Gurnee	Lake	67	317 (821)	4
	Ball Corp.	Mundelein	Lake	67	317 (821)	1
	Hillsboro Glass Co.	Hillsboro	Montgomery	75	16 (42.3)	1
	Kerr Glass Mfg. Co.	Plainfield	Will	67	275 (712)	2
	Metro Containers	Dolton	Cook	67	2197 (5689)	3
	Obear-Nester Glass Co.	East St. Louis	St. Clair	70	161 (417)	3
	Obear-Nester Glass Co.	Lincoln	Logan	75	20 (52.9)	2
	Owens-Illinois	Alton	Madison	70	130 (337)	8
	Owens-Illinois	Chicago Heights	Cook	67	2197 (5689)	
	Owens-Illinois	Streator	LaSalle	71	37 (96)	9
	Thatcher Glass Mfg. Co.	Streator	LaSalle	37	37 (96)	2
	Universal Glass Products Co.	Joliet	Will	67	275 (712)	1
Indiana	Anchor Hocking Corp.	Winchester	Randolph	76	24 (63)	3
	Brockway Glass Co., Inc.	Lapel	Madison	76	117 (304)	2
	Foster-Forbes Glass Co.	Marion	Grant	76	77 (199)	5
	Glass Containers Corp.	Indianapolis	Marion	80	758 (1963)	2
	Glass Containers Corp.	Gas City	Grant	76	77 (199)	
	Kerr Glass Mfg. Co.	Dunkirk	Jay	76	23 (60.3)	3
	Midland Glass Co.	Terre Haute	Vigo	84	105 (272)	3
	Owens-Illinois	Gas City	Grant	76	77 (199)	3
	Thatcher Glass Mfg. Co.	Lawrenceburg	Dearborn	79	37 (94.9)	2
Louisiana	Laurens Glass Co.	Ruston	Lincoln	22	27 (69.2)	4
	Owens-Illinois	New Orleans	Orleans	106	1102 (2854)	2
	Underwood Glass Co.	New Orleans	Orleans	106	1102 (2854)	5

TABLE A-1. (Continued)

State	Plant	City	County	AQCR	County Population Density, persons/km^2 (persons/mi^2)	Furnaces
Maryland	Carr-Lowrey Glass Co.	Baltimore	Baltimore	115	976 (2527)	3
	Columbia Glass Co.	Baltimore	Baltimore	115	976 (2527)	
	Maryland Glass Corp.	Baltimore	Baltimore	115	976 (2527)	4
Massachusetts	Foster-Forbes Glass Co.	Milford	Worchester	120	162 (419)	1
	Owens-Illinois	Mansfield	Bristol	120	307 (796.3)	2
Michigan	Owens-Illinois	Charlotte	Eaton	125	46 (120)	3
Minnesota	Brockway Glass Co.	Rosemount	Dakota	131	93 (241)	2
	Midland Glass Co.	Shakopee	Scott	131	35 (91)	2
Mississippi	Chattanooga Glass Co.	Gulfport	Harrison	5	87 (224)	4
	Glass Containers Corp.	Jackson	Hinds	5	92 (239)	1
	Underwood Glass Co.	Mineral Wells	Union	135	17 (44.2)	8
New Jersey	Anchor Hocking Corp.	Salem	Salem	45	7 (17)	3
	Brockway Glass Co.	Freehold	Monmouth	43	369 (955)	2
	Gayner Glass Works	Salem	Salem	45	7 (17)	3
	Kerr Glass Mfg. Corp.	Millville	Cumberland	150	92 (238)	5
	Leone Industries	Bridgeton	Cumberland	150	92 (238)	1
	Metro Containers	Jersey City	Hudson	43	4907 (12703)	2
	Metro Containers	Carteret	Middlesex	43	714 (1849)	2
	Midland Glass Co.	Cliffwood	Monmouth	43	369 (955)	4
	Owens-Illinois	Bridgeton	Cumberland	150	92 (238)	8
	Owens-Illinois	N. Bergen	Hudson	43	4907 (12703)	4
	Thatcher Glass Mfg. Co.	Wharton	Morris	43	314 (813)	2
	Wheaton Industries	Millville	Cumberland	150	92 (238)	23

TABLE A-1. (Continued)

State	Plant	City	County	AQCR	County Population Density, persons/km^2 (persons/mi^2)	Furnaces
New York	Glenshaw Glass Co.	Orangeburg	Rockland	43	502 (1300)	2
	Leone Industries	Rochester	Monroe	160	404 (1047)	3
	Owens-Illinois	Brockport	Monroe	160	404 (1047	3
	Thatcher Glass Mfg. Co.	Elmira	Chemung	164	94 (243)	3
North Carolina	Ball Corporation	Asheville	Buncombe	171	81 (210)	1
	Laurens Glass Co.	Henderson	Vance	166	51 (131)	1
	Owens-Illinois	Winston-Salem	Forsyth	136	189 (490)	3
Ohio	Brockway Glass Co., Inc.	Zanesville	Muskingum	183	45 (116)	3
	Chattanooga Glass Co.	Mt. Vernon	Know	175	31 (79)	
Oklahoma	Ball Corp.	Okmulgee	Okmulgee	186	19 (49)	1
	Bartlett-Collins Co.	Sapulpa	Creek	186	19 (48)	2
	Brockway Glass Co.	Ada	Pontotoc	188	15 (38)	1
	Brockway Glass Co.	Muskogee	Muskogee	186	27 (70)	2
	Kerr Glass Mfg. Corp.	Sand Springs	Tulsa	186	14 (37)	1
	Liberty Glass Co.	Sapulpa	Creek	186	19 (48)	4
Oregon	Owens-Illinois	Portland	Multnomah	193	500 (1295)	4
Pennsylvania	Anchor Hocking Corp.	Connellsville	Fayette	197	75 (193)	5
	Brockway Glass Co.	Brockway	Jefferson	178	25 (66)	2
	Brockway Glass Co.	Crenshaw		178	25 (66)	2
	Brockway Glass Co.	Washington	Washington	197	94 (244)	4
	Brockway Glass Co.	Washington	Washington	197	94 (244)	3
	Diamond Glass Co.	Royersford	Montgomery	45	490 (1268)	
	Foster-Forbes Glass Co.	Oil City	Venango	178	35 (90)	2
	Glass Containers Corp.	Marienville	Forest	178	4 (10)	1

TABLE A-1. (Continued)

State	Plant	City	County	AQCR	County Population Density, persons/km^2 (persons/mi^2)	Furnaces
	Glass Containers Corp.	Parker	Butler	197	61 (157)	1
	Glass Containers Corp.	Knox	Clarion	178	24 (63)	2
	Glenshaw Glass Co.	Glenshaw	Allegheny	197	842 (2180)	4
	Metro Containers	Washington	Washington	197	94 (244)	1
	Owens-Illinois	Clarion	Clarion	178	24 (63)	2
	Pennsylvania Glass Products Co.	Pittsburgh	Allegheny	197	842 (2180)	
	Pierce Glass Co.	Port Allegheny	McKean	178	20 (51)	3
Rhode Island	Star City Glass Co.	Coventry	Kent	120	315 (817)	2
South Carolina	Laurens Glass Co.	Laurens	Laurens	203	26 (68)	9
Tennessee	Chattanooga Glass Co.	Chattanooga	Hamilton	55	170 (441)	5
Texas	Anchor Hocking Corp.	Houston	Harris	216	386 (1000)	4
	Chattanooga Glass Co.	Corsicana	Navarro	215	11 (28)	3
	Glass Containers Corp.	Palestine	Anderson	22	10 (26)	2
	Kerr Glass Mfg. Corp.	Waxahachie	Ellis	215	19 (48)	1
	Owens-Illinois	Waco	McLennan	212	54 (139)	4
Washington	Northwestern Glass	Seattle	King	229	207 (536)	6
West Virginia	Prockway	Clarksburg	Harrison	235	66 (171)	6
	Chattanooga Glass Co.	Keyser	Mineral	113	27 (69)	1
	Kerr Glass Mfg. Corp.	Huntington	Cabell	103	144 (373)	1
	Owens-Illinois	Fairmont	Marion	235	75 (194)	5
	Owens-Illinois	Huntington	Cabell	103	144 (373)	5
	Universal Glass Products Co.	Parkersburg	Wood	179	88 (229)	1
Wisconsin	Foster-Forbes Glass Co.	Burlington	Kenosha	239	166 (429)	2

APPENDIX B

EMISSIONS DATA

Raw Materials Preparation and Handling

Five typical points for particulate emissions were considered for the raw materials preparation and handling operations: (1) unloading and conveying, (2) crushing of cullet (scrap glass), (3) filling and emptying of storage bins, (4) weighing and mixing of batch, and (5) feeding of batch to glass melting furnace (batch charging). Source test data are summarized in Table B-1.

Emissions from the raw materials preparation and handling operation consist entirely of particulates from raw batch materials. In practice, only fugitive dust emissions should be considered, since particulate emissions remaining within the plant may constitute an OSHA health and safety consideration distinct from plant emissions. As discussed in the text, only particles below 100 micron are considered as contributing to figitive dust emissions. Actual measurements of plant emissions from these operations were not available; however, personal observation indicates that there are no visible emissions from the batch house. Measurements were available from NEDS(14) of particulate emissions within a few plants. These were used to determine particulate emissions on a worst-case basis.

The average emission factors for the various raw material preparation and handling operations were taken to be the following, calculated on a worst-case basis.

		mg/kg
1.	Handling	22 ± 100%
2.	Crushing	1 ± 100%
3.	Storage	1 ± 100%
4.	Mixing	5 ± 100%
5.	Charging	<0.1
		29 ± 100%

TABLE B-1. SUMMARY OF SOURCE TEST DATA FOR MATERIALS PREPARATION AND HANDLING(a)

Particulate Emissions		Production		Rate		
Mg/yr	(Tons/yr)	Gg/yr	(Tons/yr)	mg/kg (lb/ton)	Control Equipment	Operation
3.63	(4.0)	7.53	(830,000)	5.0 (0.010)	fabric filters	hand and storage
0.91	(1.0)	87.8	(96,800)	10.5 (0.021)	fabric filters	batch house
	trace(a)	121.5	(134,000)	0.0	fabric filters	crushing
0.91	(1.0)	231.2	(255,000)	4.0 (0.008)	fabric filters	mixing
4.54	(5.0)	231.2	(255,000)	19.5 (0.039)	fabric filters	delivery
trace(b)		12.8	(14,100)	0.0	fabric filters	storage
0.91	(1.0)	276.6	(305,000)	3.5 (0.007)	fabric filters	mixing
	trace(b)	134.2	(148,000)	0.0	fabric filters	storage
	trace(b)	276.6	(305,000)	0.0	fabric filters	storage
	trace(b)	257.6	(284,000)	0.0	fabric filters	mixing
3.63	(4.0)	165.1	(182,000)	22.0 (0.044)	fabric filters	conveying

(a) Source NEDS(14)

(b) Trace < 1.0.

Total annual emissions were based on 15.8 Tg of raw materials being processed to melt 12.7 Tg of glass. This assumes that 85 percent of glass melted produces a saleable container.

Stack heights for these and other plant operations are listed in Appendix C. They range from 5 m (16 feet) to 44 m (144 feet).

The accuracy was only obtainable for batch mixing where the sample mean was 4.5 mg/kg and the sample standard deviation was 2.0 mg/kg. The 95 percent confidence level was ± 3.187 mg/kg. The accuracy of engineering estimates was assumed to be ± 100 percent.

Glass Melting

Nitrogen Oxides

Source test measurements of NO_x emissions from NEDS$^{(14)}$ are listed in Table B-2. Emission factors vary from 0.58 to 6.29 g/kg (1.60 to 12.40 lb/ton), which clearly reflect the wide range of operating conditions found in glass melting furnaces. The average emission factor of 3.07 g/kg (6.14 lb/ton) assumes 85 percent of the glass melted is flint (clear or green) which has an average emission factor of 3.40 g/kg and 15 percent is amber, which has an average emission factor of 1.22 g/kg. The average emission factors for these two glass types was determined by adding the average emission factors together and dividing by the number of values. Alternatively, the average found by dividing the total emissions by total production was 3.20 g/kg (6.40 lb/ton). The difference is not significant because the standard deviation is ± 3.2 g/kg, and the 95 percent confidence level is ± 1.469 g/kg.

Standard deviations (σ) were determined by the following method.

$$\sigma = \left[\frac{1}{m} \sum_{i=o}^{m} (N_i - \mu)^2 \right]^{1/2}$$

TABLE B-2. NO_x EMISSIONS FROM GLASS CONTAINER FURNACES

	Production		Emissions		Emission Factor	
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)
Flint						
1	46.1	(50.800)	5.08	(56)	1.10	(2.20)
2	58.8	(64,800)	50.8	(56)	0.86	(1.72)
3	70.1	(77,300)	349.3	(385)	4.98	(9.96)
4	38.7	(42,700)	38.1	(42)	0.98	(1.96)
5	56.2	(62,000)	151.5	(167)	2.69	(5.38)
6	40.0	(44,100)	51.7	(57)	1.29	(2.58)
7	47.6	(52,500)	299.4	(330)	6.29	(12.58)
8	31.8	(35,100)	167.8	(185)	5.27	(10.54)
9	11.8	(13,000)	62.6	(69)	5.31	(10.62)
10	34.7	(38,300)	184.2	(203)	5.30	(10.60)
11	47.8	(52,700)	253.1	(279)	5.29	(10.58)
12	36.5	(40,300)	226.8	(250)	6.20	(12.40)
13	41.3	(45,500)	117.9	(130)	2.86	(5.72)
14	98.9	(109,000)	381.0	(420)	3.85	(7.72)
15	34.7	(38,300)	49.9	(55)	1.44	(2.88)
16	71.0	(78,300)	78.0	(86)	1.10	(2.20)
17	161.5	(178,000)	733.9	(809)	4.55	(9.10)
18	66.2	(73,000)	198.7	(219)	3.00	(6.00)
19	53.5	(59,000)	198.7	(219)	3.71	(7.42)
20	41.1	(45,300)	198.7	(219)	4.83	(9.66)
21	49.9	(55,000)	29.9	(33)	0.58	(1.16)
Amber						
22	14.3	(15,800)	17.2	(19)	1.21	(2.41)
23	28.6	(31,500)	35.4	(39)	1.24	(2.48)
24	37.8	(41,700)	46.2	(51)	1.22	(2.45)
Average*	50.1	(55,200)	153.8	(170)	3.07	(6.14)

* Assumes 85% of glass is Flint and 15% Amber. Average is a weighted sum of averages for these two glass types.

where: m = number of samples

N_i = sample value

μ = sample mean.

The confidence interval (CI) was determined by

$$CI = \frac{k\sigma}{m^{1/2}}$$

where: k = "Student's t" variable for $m-1$ degrees of freedom.

Sulfur Oxides

Source test measurements of SO_x emissions from NEDS(14) are listed in Table B-3. Emission factors vary from 0.21 to 8.35 g/kg (0.41 to 16.7 lb/ton). The average emission factor of 1.70 g/kg (3.4 lb/ton) is based upon 85 percent flint glass having an average emission factor of 1.84 g/kg and 15 percent amber having an average emission factor of 0.93 g/kg. The standard deviation is 2.2 g/kg and the 95 percent confidence level is ± 0.66 g/kg.

SO_x emissions are believed to come entirely from natural gas fired glass melting furnaces. Increased use of oil would increase both the rate and amoung of emissions.

Particulates

Source test measurements of particulate emissions obtained from NEDS(14) are listed in Table B-4. Emission factors vary from 0.13 to 1.95 g/kg (0.27 to 3.90 lb/ton). The average emission factor of 0.68 g/kg (1.35 lb/ton) is based on 85 percent flint glass having an emission factor of 0.71 g/kg and 15 percent amber glass having an average emission factor of 0.48 g/kg. The standard deviation is 1.0 g/kg and the 95 percent confidence interval is ± 0.25.

TABLE B-3. SO_x EMISSIONS FROM GLASS CONTAINER FURNACES

	Production		Emissions		Emission Factor	
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)
Flint						
1	46.1	(50,800)	27.2	(30)	0.59	(1.18)
2	49.9	(55,000)	36.3	(40)	0.67	(1.34)
3	15.9	(17,500)	8.2	(09)	0.51	(1.02)
4	56.6	(62,400)	79.8	(88)	1.41	(2.82)
5	40.0	(44,100)	94.4	(104)	2.36	(4.72)
6	73.9	(81,500)	104.3	(115)	1.41	(2.82)
7	47.6	(52,500)	122.5	(135)	2.57	(5.14)
8	55.3	(60,900)	435.5	(480)	7.88	(15.76)
9	31.8	(35,100)	16.3	(18)	0.51	(1.02)
10	58.8	(64,800)	27.2	(30)	0.46	(0.98)
11	11.8	(13,000)	6.4	(07)	0.54	(1.08)
12	38.7	(42,700)	49.9	(55)	1.28	(2.56)
13	34.8	(38,300)	17.2	(19)	0.50	(1.00)
14	45.6	(50,300)	381.0	(420)	8.35	(16.70)
15	47.8	(52,700)	24.5	(27)	0.51	(1.02)
16	80.6	(88,800)	184.2	(203)	2.59	(5.18)
17	34.8	(38,300)	10.9	(12)	0.31	(0.62)
18	57.4	(63,300	208.7	(230)	3.63	(7.26)
19	71.0	(78,300)	52.6	(58)	0.74	(1.48)
20	54.5	(60,100)	381.0	(420)	6.99	(13.98)
21	41.0	(45,200)	10.9	(12)	0.27	(0.54)
22	57.9	(63,800)	208.7	(230)	3.61	(7.22)
23	30.0	(33,100)	9.1	(10)	0.30	(0.60)
24	64.3	(70,900)	381.0	(420)	5.92	(11.84)
25	81.7	(90,000)	65.3	(72)	0.80	(1.60)
26	103.9	(115,000)	208.7	(230)	2.00	(4.00)
27	81.5	(90,000)	39.0	(43)	0.48	(0.96)
28	44.5	(49,000)	69.0	(76)	1.55	(3.10)
29	81.5	(90.000)	70.0	(77)	0.86	(1.72)
30	57.2	(63,000)	11.8	(13)	0.21	(0.42)
31	161.5	(178,000)	110.7	(122)	0.69	(1.38)
32	50.8	(56,000)	72.6	(80)	1.43	(2.86)
33	66.2	(73,000)	79.8	(88)	1.21	(2.42)
34	60.3	(66,500)	49.9	(55)	0.83	(1.66)
35	53.5	(59,000)	59.9	(66)	1.12	(2.24)
36	72.6	(80,000)	108.9	(120)	2.14	(4.28)
37	41.1	(45,300)	59.9	(66)	1.47	(2.94)
38	33.6	(37,000)	64.4	(71)	1.92	(3.84)
39	51.7	(57,000)	96.2	(106)	1.86	(3.72)
40	14.3	(15,800)	39.0	(43)	2.72	(5.44)
41	14.3	(15,800)	39.0	(43)	2.72	(5.44)
42	34.5	(38,000)	145.2	(160)	4.21	(8.42)
43	37.2	(41,000)	38.1	(42)	1.02	(2.04)

TABLE B-3. (Continued)

	Production		Emissions		Emission Factor	
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)
44	73.2	(80,700)	53.5	(59)	0.73	(1.46)
45	98.9	(109,000)	45.4	(50)	0.46	(0.92)
46	35.3	(38,900)	10.0	(11)	0.28	(0.56)
Amber						
47	14.3	(15,800)	4.5	(05)	0.32	(0.63)
48	28.6	(31,500)	58.9	(65)	2.06	(4.13)
49	37.8	(41,700)	15.4	(17)	0.41	(0.82)
Average*	50.1	(55,200)	85.2	(94)	1.70	(3.40)

* Assumes 85% of glass is Flint and 15% Amber. Average is a weighted sum of averages for these two glass types.

TABLE B-4. PARTICULATE EMISSIONS FROM GLASS CONTAINER FURNACES

	Production		Emissions		Emission Factor	
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)
Flint						
1	46.1	(50,800)	35.4	(39)	0.77	(1.54)
2	81.7	(90,000)	39.0	(43)	0.48	(0.96)
3	15.9	(17,500)	5.4	(6)	0.34	(0.68)
4	161.5	(178,000)	161.5	(178)	1.00	(2.00)
5	40.0	(44,100)	23.6	(26)	0.59	(1.18)
6	66.2	(73,000)	43.6	(48)	0.66	(1.32)
7	47.6	(52,500)	26.3	(29)	0.55	(1.10)
8	53.5	(59,000)	39.9	(44)	0.75	(1.50)
9	31.8	(35,100)	23.6	(26)	0.74	(1.48)
10	41.1	(45,300)	36.3	(40)	0.88	(1.76)
11	11.8	(13,000)	9.1	(10)	0.77	(1.54)
12	49.9	(55,000)	11.8	(13)	0.24	(0.48)
13	34.7	(38,300)	26.3	(29)	0.76	(1.52)
14	60.3	(66,500)	17.2	(19)	0.29	(0.58)
15	47.8	(52,700)	26.3	(40)	0.76	(1.52)
16	56.6	(62,400)	20.9	(23)	0.37	(0.74)
17	752.8	(830,000)	677.7	(747)	0.90	(1.80)
18	73.9	(81,500)	28.1	(31)	0.38	(0.76)
19	34.8	(38,300)	33.6	(37)	0.97	(1.94)
20	55.3	(60,900)	31.8	(35)	0.57	(1.14)
21	71.0	(78,300)	61.7	(68)	0.87	(1.74)
22	58.8	(64,800)	35.4	(39)	0.60	(1.20)
23	65.4	(72,100)	64.4	(71)	0.98	(1.96)
24	38.7	(42,700)	27.2	(30)	0.70	(1.40)
25	68.0	(74,900)	43.6	(48)	0.64	(1.28)
26	45.6	(50,300)	16.3	(18)	0.36	(0.72)
27	65.3	(72,000)	48.1	(53)	0.74	(1.48)
28	80.6	(88,800)	39.9	(44)	0.50	(1.00)
29	41.0	(45,200)	35.4	(39)	0.86	(1.72)
30	57.4	(63,300)	16.3	(18)	0.28	(0.56)
31	30.0	(33,100)	22.7	(25)	0.76	(1.52)
32	54.5	(60,100)	16.3	(18)	0.30	(0.60)
33	66.0	(72,800)	36.3	(40)	0.55	(1.10)
34	57.9	(63,800)	39.9	(44)	0.69	(1.38)
35	81.7	(90,000)	69.9	(77)	0.86	(1.72)
36	64.3	(70,900)	16.3	(18)	0.25	(0.50)
37	81.7	(90,000)	49.9	(55)	0.61	(1.22)
38	104.3	(115,000)	39.9	(44)	0.38	(0.76)
39	44.5	(49,000)	11.8	(13)	0.36	(0.72)
40	57.2	(63,000)	21.8	(24)	0.38	(0.76)
41	50.8	(56,000)	27.2	(30)	0.54	(1.08)
42	60.3	(66,500)	17.3	(19)	0.29	(0.58)

TABLE B-4. (Continued)

	Production		Emissions		Emission Factor	
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)
43	72.6	(80,000)	57.2	(63)	1.13	(2.26)
44	33.6	(37,000)	8.2	(09)	0.24	(0.48)
45	51.7	(57,000)	25.4	(28)	0.49	(0.98)
46	14.3	(15,800)	13.6	(15)	0.95	(1.90)
47	14.3	(15,800)	13.6	(15)	0.95	(1.90)
48	34.5	(38,000)	26.3	(29)	0.76	(1.52)
49	74.4	(82,000)	47.2	(52)	0.63	(1.26)
50	66.2	(73,000)	45.4	(50)	0.68	(1.36)
51	69.9	(77,000)	89.8	(99)	1.29	(2.58)
52	76.2	(84,000)	107.1	(118)	1.40	(2.80)
53	10.9	(120,000)	119.8	(132)	1.10	(2.20)
54	37.2	(41,000)	34.5	(38)	0.93	(1.86)
55	16.4	(18,100)	3.6	(04)	0.22	(0.44)
56	8.9	(9,800)	7.3	(08)	0.81	(1.62)
57	19.3	(21,300)	10.9	(12)	0.56	(1.12)
58	64.8	(71,400)	111.6	(123)	1.72	(3.44)
59	55.9	(61,600)	104.3	(115)	1.87	(3.74)
60	57.3	(63,200)	111.6	(123)	1.95	(3.90)
61	165.1	(182,000)	99.8	(110)	1.61	(3.22)
62	73.2	(80,700)	33.6	(37)	0.46	(0.92)
63	98.9	(109,000)	25.4	(28)	0.26	(0.52)
64	35.3	(38,900)	21.8	(24)	0.62	(1.24)
65	30.9	(34,100)	14.5	(16)	0.47	(0.94)
66	35.7	(39,300)	20.0	(22)	0.56	(1.12)
Amber						
67	14.3	(15,800)	6.4	(7)	0.44	(0.88)
68	28.6	(31,500)	10.0	(11)	0.35	(0.70)
69	37.8	(41,700)	8.2	(9)	0.22	(0.44)
70	3.9	(4,345)	2.7	(3)	0.69	(1.38)
71	3.9	(4,345)	2.6	(2.9)	0.67	(1.34)
72	3.9	(4,345)	2.9	(3.2)	0.74	(1.48)
73	3.9	(4,315)	2.6	(2.9)	0.67	(1.34)
74	3.9	(4,345)	2.6	(2.9)	0.67	(1.34)
75	2.8	(3,121)	1.2	(1.3)	0.43	(0.86)
76	2.8	(3,121)	1.3	(1.4)	0.46	(0.92)
77	2.8	(3,121)	1.2	(1.3)	0.43	(0.86)
78	1.7	(1,836)	1.3	(1.4)	0.76	(1.42)
79	1.1	(1,224)	0.91	(1.0)	0.83	(1.66)
80	0.98	(1,083)	0.64	(0.7)	0.65	(1.30)
81	0.98	(1,083)	0.54	(0.6)	0.55	(1.10)
82	0.98	(1,083)	0.64	(0.7)	0.65	(1.30)
83	0.98	(1,083)	0.73	(0.8)	0.74	(1.48)

TABLE B-4. (Continued)

	Production		Emissions		Emission Factor	
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)
84	47.9	(52,836)	2.1	(2.3)	0.04	(0.08)
85	43.3	(47,712)	6.6	(7.3)	0.15	(0.30)
86	43.3	(47,712)	12.0	(13.2)	0.28	(0.56)
87	29.3	(32,327)	3.9	(4.3)	0.13	(0.27)
88	44.7	(49,316)	12.4	(13.7)	0.28	(0.56)
89	44.6	(49,140)	8.2	(9.0)	0.18	(0.36)
Average*	58.1	(64,000)	39.3	(43.3)	0.66	(1.35)

* Assumes 85% of glass is Flint and 15% Amber. Average is a weighted sum of averages for these two glass types.

Carbon Monoxide

Source test measurements of carbon monoxide emissions are limited because this is not a major glass furnace emission. It can form because the industry uses a long diffusion flame to effect uniform heat release. Properly controlled, the emissions are negligible. The emissions are listed in Table B-5. Emission factors vary from 0.05 to 0.13 g/kg (0.09 to 0.25 lb/ton). The average emission factor of 0.7 g/kg (0.13 lb/ton) is based on 85 percent flint glass having an emission factor of 0.06 g/kg and 15 percent amber glass having an emission factor of 0.11 g/kg. The standard deviation was 0.2 g/kg and the 95 percent confidence level was 0.10 g/kg.

Hydrocarbons

Source test measurements of hydrocarbon emissions are also limited. Formation occurs for the same reasons as cited for carbon monoxide. These emissions are listed in Table B-6. Emission factors vary from 0.01 to 0.53 g/kg (0.02 to 1.06 lb/ton). The average emission factor of 0.08 g/kg (0.150 lb/ton) is based on 85 percent flint glass having an average emission factor of 0.08 g/kg and 15 percent amber glass having an average emission factor of 0.05 g/kg. The standard deviation is 0.5 g/kg, and the 95 percent confidence interval is ± 0.178 g/kg.

Selenium

No source test measurements are available for selenium emissions from flint glass furances. Using data supplied by GCMI(2) and obtained from the technical literature, a worst-case engineering calculation was made. Selenium is used as a decolorizer to neutralize the tint from transition metal oxide contaminants such as iron. Approximately 0.36 Gg (395 tons) of selenium are consumed annually in the U.S., of which about one-sixth is used by glass container industry (0.06 Gg).(2) If it is assumed that 40 percent of the selenium used volatilizes and is emitted from the melting furnace, then the emission rate would be 0.002 g/kg. The accuracy of this calculation was taken

TABLE B-5. CO EMISSIONS FROM GLASS CONTAINER FURNACES

	Production		Emissions		Emission Factor	
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)
Flint						
1	65.3	(72,000)	3.6	(4)	0.06	(0.11)
2	65.3	(72,000)	3.6	(4)	0.06	(0.11)
3	53.5	(59,000)	2.7	(3)	0.05	(0.10)
4	41.1	(45,300)	2.7	(3)	0.07	(0.13)
5	49.9	(55,000)	4.5	(5)	0.09	(0.18)
6	60.3	(66,500)	5.4	(6)	0.09	(0.18)
7	56.6	(62,400)	3.6	(4)	0.06	(0.12)
8	73.9	(81,500)	3.6	(4)	0.05	(0.10)
9	55.3	(60,900)	3.6	(4)	0.07	(0.13)
10	22.9	(25,200)	1.8	(2)	0.08	(0.16)
11	16.4	(18,100)	0.91	(1)	0.06	(0.11)
12	18.6	(20,500)	0.91	(1)	0.05	(0.10)
13	102.5	(113,000)	6.4	(7)	0.06	(0.12)
14	74.4	(82,000)	3.6	(4)	0.05	(0.10)
15	66.2	(73,000)	3.6	(4)	0.05	(0.10)
16	69.9	(77,000)	3.6	(4)	0.05	(0.10)
17	76.2	(84,000)	3.6	(4)	0.05	(0.10)
18	30.9	(34,100)	2.7	(3)	0.09	(0.18)
19	35.7	(39,300)	3.6	(4)	0.10	(0.20)
Amber						
20	14.3	(15,800)	1.8	(2)	0.12	(0.25)
21	28.6	(31,500)	2.7	(3)	0.09	(0.19)
22	37.8	(41,700)	3.6	(4)	0.10	(0.19)
Average*	50.3	(55,500)	3.1	(3)	0.07	(0.13)

* Assumes 85% of glass is Flint and 15% Amber. Average is a weighted sum of averages for these two glass types.

TABLE B-6. HC EMISSIONS FROM GLASS CONTAINER FURNACES

	Production		Emissions		Emission Factor	
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)
Flint						
1	32.7	(36,000)	17.2	(19)	0.53	(1.06)
2	34.8	(38,300)	5.4	(6)	0.16	(0.31)
3	71.0	(78,300)	7.3	(8)	0.10	(0.20)
4	65.4	(72,100)	0.8	(1)	0.01	(0.03)
5	67.9	(74,900)	7.3	(8)	0.11	(0.21)
6	65.3	(72,000)	10.0	(11)	0.16	(0.31)
7	95.2	(105,000)	12.7	(14)	0.13	(0.27)
8	105.2	(116,000)	12.7	(14)	0.12	(0.24)
9	65.3	(72,000)	0.9	(1)	0.01	(0.03)
10	65.3	(72,000)	0.9	(1)	0.01	(0.03)
11	53.5	(59,000)	0.9	(1)	0.02	(0.03)
12	41.1	(45,300)	0.9	(1)	0.02	(0.04)
13	49.9	(55,000)	2.7	(3)	0.05	(0.10)
14	60.3	(66,500)	2.7	(3)	0.05	(0.09)
15	56.6	(62,400)	0.9	(1)	0.02	(0.03)
16	73.9	(81,500)	1.8	(2)	0.02	(0.03)
17	55.2	(60,900)	1.8	(2)	0.02	(0.05)
18	22.9	(25,200)	0.9	(1)	0.03	(0.07)
19	102.5	(113,000)	0.9	(1)	0.04	(0.08)
20	72.6	(80,000)	6.4	(7)	0.01	(0.02)
21	33.6	(37,000)	3.6	(4)	0.09	(0.18)
22	51.7	(57,000)	3.6	(4)	0.11	(0.22)
23	14.3	(15,800)	1.8	(2)	0.07	(0.14)
24	14.3	(15,800)	1.8	(2)	0.12	(0.25)
25	34.5	(38,000)	2.7	(3)	0.12	(0.25)
26	74.4	(82,000)	1.8	(2)	0.08	(0.16)
27	66.2	(73,000)	1.8	(2)	0.02	(0.05)
28	69.9	(77,000)	1.8	(2)	0.03	(0.05)
29	76.2	(84,000)	1.8	(2)	0.03	(0.05)
30	64.4	(71,000)	9.1	(10)	0.02	(0.05)
31	56.3	(62,000)	7.3	(8)	0.14	(0.28)
32	30.9	(34,100)	0.9	(1)	0.13	(0.26)
33	35.7	(39,300)	1.8	(2)	0.03	(0.06)
					0.05	(0.10)
Amber						
34	14.3	(15,800)	0.9	(1)	0.06	(0.13)
35	28.6	(31,500)	0.9	(1)	0.03	(0.06)
36	37.8	(41,700)	1.8	(2)	0.05	(0.10)
Average*	53.4	(58,900)	4.0	(5)	0.08	(0.15)

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* Assumes 85% of glass is Flint and 15% Amber. Average is a weighted sum of averages for these two glass types.

as ± 100 percent. This is determined by dividing the total selenium (0.06 Gg) by the total glass melted (12.7 Tg) and multiplying by 0.4 (the amount of selenium emitted) alternately, the selenium represents no more than 0.001 percent of the glass or 0.008 g/kg of glass produced.(32) If 75 percent of the production contains selenium, then the emission rate would also be 0.002 g/kg. This is determined by dividing 0.01 g/kg (amount of selenium) by 1.25 (batch to produce 1 unit of glass) and then multiplying by 0.40 (percent selenium emitted) and 0.75 (percent glass using selenium).

Forming and Finishing

Emissions measurements from the forming and finishing operations were not available; hence, engineering calculations, considering worst-case situations, were used to determine the severity of emissions from this area.

Forming

During forming, an emulsion containing oil or silicone and water is sprayed onto the molds. Approximately 1.4 g (1/20 ounce) of liquid is sprayed per container produced. If one assumes that only oil is used as a lubricant (silicone is also popular) and that the mixture of oil to water is 1:125, a normal situation. Then under these conditions, the emission rate would be 0.035 g/kg, considering the production in 1974 of approximately 40 billion containers and 12.7 Tg.(2) These were considered minor. The calculation is shown below. Accuracy is taken to be ± 100%.

Oil/container - 1.4 g ÷ 125 = 0.0112 g
Container weight - 12.7×10^{12} g ÷ 40×10^{9} containers = 0.318 kg/container
Emission rate - 0.0112 ÷ 0.318 = 0.035 g/kg

Surface Treatment

Approximately 30 percent of containers produced receive a surface treatment to improve resistance to scratching and to facilitate handling.

Hot containers are subjected to a tin or titanium chloride vapor. Emissions consist of metal oxide and hydrated metal chloride particulates and HCl.

Data received from glass container manufacturers showed the average consumption of material in surface treatment operations was 0.12 g/kg (0.24 lb/ton), of which 60 percent or 0.07 g/kg (0.14 lb/ton) escapes to the atmosphere. This is composed of 22 percent metal oxide, 44 percent hydrated metal chloride, and 34 percent HCl. Emission rates were then calculated for tin compounds to be 0.02 g/kg (0.03 lb/ton) of tin chloride, 0.03 g/kg (0.06 lb/ton) of hydrated tin chloride, and 0.02 g/kg (0.05 lb/ton) of HCl. These are based on the tin compounds comprising approximately 40 percent of the total weight input and HCl approximately 20 percent of the total weight input. Accuracy of the data was taken as ± 100 percent.

Annealing

No emission data were available for gas-fired annealing lehrs; therefore, emission factors were estimated from other data on gas combustion. A modern recirculating air type lehr consumes 11 to 17 m^3/hr (400 cfh to 600 cfh) when annealing 91 Gg (100 tons) of glass per day. Lehrs of older design can consume 34 to 57 m^3/hr (1200 cfh to 2000 cfh)(52). On a worst case basis (57 M^3/hr) would require 0.0062 m^3/kg of glass produced. For a plant producing 319 Mg/day (352 ton/day) this would amount to 91 m^3/hr. With a heating value of natural gas (1000 Btu/cf or 37.3 million joules/m^3) this amounts to 0.93 million joules per second or about 0.23 million joules per kg of glass (200,000 Btu/ton).

Using tests on gas-fired burners(53), emission data was determined as shown in Table B-7. Converting these on a basis of 0.24 million joules/kg of glass gave the emission factors for annealing shown in Table B-8.

Decorating

Glass containers are sometimes decorated with vitrifiable glass enamels or organic materials. Emissions are derived from organic solvents and binders used in the coatings. Data supplied by glass manufacturers

TABLE B-7. EMISSIONS FROM GAS-FIRED BURNERS(53)

Test	Emissions, mg/kg				
	NO_x	SO_x	Particulates	CO	Hydrocarbons
15	60.2	-	9.0	5.6	1.29
17	150	0	2.58	8.6	-
18	38.7	0	3.0	11.2	9.5
19	25.8	-	11.2	12.9	6.9
Average and 95% confidence limits	69 ±113%	0	5.2 ±196%	9.5 ±55%	6.0 ±144%
Standard deviation	±47	0	±5.2	±2.75	±3.4

TABLE B-8. EMISSION FACTORS FOR ANNEALING LEHRS

Emission	Emission factor	
	mg/kg	(lb/ton)
NO_x	16 ± 113%	(0.032)
SO_x	0	(0)
Particulates	1.2 ± 196%	(0.0024)
CO	2.2 ± 55%	(0.0044)
Hydrocarbons	1.4 ± 144%	(0.0028)

would indicate that only 3 percent of containers are coated. Point source emission data were not available. Materials balances taken from NEDS(14) were used as the basis for estimating the emission rate for hydrocarbons from decorating lehrs. Table B-9 lists the emission data. The hydrocarbon emission rate was 4.37 g/kg (8.73 lb/ton). The total hydrocarbons emitted annually from all sources is estimated to be 1.44 Gg (1,590 tons). This was determined in the following manner.

1974 container shipments = 11.005×10^{12} g
Decorated container (3%) = 330.1×10^{9} g
Total Emissions = Shipments x Emission Rate = 1.44×10^{9} g

TABLE B-9. HC EMISSIONS FROM GLASS CONTAINER DECORATING OPERATIONS

	Production		Emissions		Emission Factor	
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)
1	21.2	(23,400)	80	(88)	3.76	(7.52)
2	20.2	(22,300)	80	(88)	3.95	(7.89)
3	15.7	(17,300)	80	(88)	5.09	(10.17)
4	15.7	(17,300)	80	(88)	5.09	(10.17)
5	20.2	(22,300)	80	(88)	3.95	(7.89)
Average	18.6	(20,500)	80	(88)	4.37	(8.73)

* Material Balance Data Taken from NEDS(14)

TABLE C-1. TYPICAL STACK HEIGHTS OF BATCH HANDLING, TREATMENT AND DECORATING OPERATIONS FOR SODA/LIME CONTAINER GLASS (14)

Batch Handling				Treatment		Decoration	
≤40 m		≥40 m					
No. of Stacks	Height, m	No. of Stacks	Height, m	No. of Stacks	Height, m	No. of Stacks	Height, m
(3)	5		44		8	(3)	12
	22				12	(2)	13
	24				13		
(4)	36			(4)	14		
				(3)	15		
					17		
					20		
				(3)	23		
				(3)	25		
					38		
Total 9	Average 23 Median 24	Total 1	Average 44 Median 44	Total 19	Average 19 Median 15	Total 5	Average 12 Median 12

TABLE C-2. TYPICAL STACK HEIGHTS OF FLINT AND AMBER CONTAINER GLASS FURNACES(14)

Flint Glass				Amber Glass	
<40		>40 m			
No. of Stacks	Height, m	No. of Stacks	Height, m	No. of Stacks	Height, m
	5	(2)	41		17
	6	(8)	43		20
	10	(3)	44		23
	12	(2)	45		
	13	(7)	46		
	14	(2)	47		
(9)	17	(3)	49		
(2)	18				
	19				
(7)	20				
(5)	21				
(15)	23				
(2)	24				
(3)	25				
(3)	26				
	27				
(7)	30				
(4)	33				
	34				
(6)	36				
(25)	38				
	39				
	40				
Total 99	Average 27	Total 27	Average 45	Total 3	Average 20
	Median 25		Median 45		Median 20

TABLE D-1. STATE LISTING OF TOTAL EMISSIONS AS OF 1972

State	Mass of emissions, metric tons/yr (upper entry) Percent of U.S. totals (lower entry)				
	Particulate	SO_2	NO_x	Hydrocarbons	CO
1 ALABAMA	2002000.0 1.53000	1228000.0 1.91000	261600.0 2.27000	342100.0 1.29000	372600.0 2.04000
2 ALASKA	16340000.0 12.50000	222800.0 0.34700	31990.0 0.27700	140800.0 0.53200	472200.0 2.58000
3 ARIZONA	3265000.0 2.49000	200200.0 0.31100	75100.0 0.65100	171100.0 0.64700	178300.0 0.97600
4 ARKANSAS	1619000.0 1.24000	205400.0 0.31900	77310.0 0.67000	281700.0 1.07000	225800.0 1.24000
5 CALIFORNIA	5675000.0 4.33000	2557000.0 3.98000	796800.0 6.91000	1914000.0 7.24000	1987000.0 10.90000
6 COLORADO	3156000.0 2.41000	473300.0 0.73600	116800.0 1.01000	294400.0 1.11000	105800.0 0.57900
7 CONNECTICUT	365600.0 0.27900	1227000.0 1.91000	152200.0 1.32000	259400.0 0.98100	92690.0 0.50700
8 DELAWARE	130200.0 0.09930	420700.0 0.65500	45720.0 0.39600	77510.0 0.29300	24580.0 0.13500
9 FLORIDA	2430000.0 1.86000	1755000.0 2.73000	410300.0 3.56000	536200.0 2.03000	3502000.0 19.20000
10 GEORGIA	2331000.0 1.78000	1635000.0 2.54000	294200.0 2.55000	526700.0 1.99000	705400.0 3.86000
11 HAWAII	251200.0 0.19200	232000.0 0.36100	40790.0 0.35400	62720.0 0.23700	84750.0 0.46400
12 IDAHO	2430000.0 1.85000	59140.0 0.09200	33220.0 0.28800	163600.0 0.61900	518300.0 2.84000
13 ILLINOIS	3584000.0 2.74000	3714000.0 5.78000	665100.0 5.77000	1343000.0 5.08000	412500.0 2.26000
14 INDIANA	2202000.0 1.68000	3036000.0 4.72000	414400.0 3.59000	675100.0 2.55000	182100.0 0.99700
15 IOWA	2579000.0 1.97000	397400.0 0.61800	137700.0 1.19000	400800.0 1.52000	90720.0 0.49700
16 KANSAS	3358000.0 2.56000	225000.0 0.35000	109900.0 0.95300	742800.0 2.81000	174600.0 0.95600
17 KENTUCKY	1854000.0 1.42000	1627000.0 2.53000	302000.0 2.62000	274600.0 1.04000	219300.0 1.20000

TABLE D-1. (Continued)

State	Mass of emissions, metric tons/yr (upper entry) Percent of U.S. totals (lower entry)				
	Particulate	SO_2	NO_x	Hydrocarbons	CO
18 LOUISIANA	1651000.0 1.26000	585800.0 0.91100	219000.0 1.90000	1741000.0 6.58000	839900.0 4.60000
19 MAINE	1038000.0 0.79200	770700.0 1.20000	54270.0 0.47000	71970.0 0.27200	61430.0 0.33600
20 MARYLAND	657300.0 0.50200	1352000.0 2.10000	215100.0 1.86000	302300.0 1.14000	163400.0 0.89400
21 MASSACHUSETTS	802700.0 0.61300	3840000.0 5.97000	322300.0 2.79000	463100.0 1.75000	190400.0 1.04000
22 MICHIGAN	2804000.0 2.14000	3513000.0 5.46000	548000.0 4.75000	734000.0 2.78000	299400.0 1.64000
23 MINNESOTA	3056000.0 2.33000	846800.0 1.32000	185000.0 1.60000	388000.0 1.47000	150700.0 0.82500
24 MISSISSIPPI	1490000.0 1.14000	280300.0 0.43600	87010.0 0.75400	350200.0 1.32000	228200.0 1.25000
25 MISSOURI	2839000.0 2.17000	1259000.0 1.96000	287500.0 2.49000	588400.0 2.22000	268500.0 1.47000
26 MONTANA	4975000.0 3.80000	177000.0 0.27500	34650.0 0.30000	174200.0 0.65800	230500.0 1.26000
27 NEBRASKA	3049000.0 2.33000	137100.0 0.21300	50940.0 0.44200	255600.0 0.96600	59590.0 0.32600
28 NEVADA	3155000.0 2.41000	263100.0 0.40900	58500.0 0.50700	36140.0 0.13700	28700.0 0.15700
29 NEW HAMPSHIRE	326500.0 0.24900	325800.0 0.50700	36060.0 0.31300	44430.0 0.16800	30240.0 0.16500
30 NEW JERSEY	815800.0 0.62300	2922000.0 4.55000	323400.0 2.80000	786600.0 2.97000	281400.0 1.54000
31 NEW MEXICO	3548000.0 2.71000	441400.0 0.68700	109800.0 0.95200	310200.0 1.17000	49460.0 0.27100
32 NEW YORK	2704000.0 2.06000	5137000.0 7.99000	721400.0 6.25000	1353000.0 5.11000	551600.0 3.02000
33 N CAROLINA	2203000.0 1.68000	2298000.0 3.58000	338400.0 2.93000	465100.0 1.76000	371500.0 2.03000
34 N DAKOTA	2854000.0 2.18000	328700.0 0.51100	61110.0 0.53000	73930.0 0.28000	22340.0 0.12200
35 OHIO	3054000.0 2.33000	4062000.0 6.32000	785800.0 6.81000	1244000.0 4.70000	482700.0 2.64000
36 OKLAHOMA	2276000.0 1.74000	163400.0 0.25400	130000.0 1.13000	674700.0 2.55000	200800.0 1.10000
37 OREGON	2885000.0 2.20000	372500.0 0.57900	62710.0 0.54400	204800.0 0.77400	304900.0 1.67000

TABLE D-1. (Continued)

State	Mass of emissions, metric tons/yr (upper entry) Percent of U.S. totals (lower entry)				
	Particulate	SO_2	NO_x	Hydrocarbons	CO
38 PENNSYLVANIA	3132000.0 2.39000	5603000.0 8.72000	782200.0 6.78000	1331000.0 5.03000	527000.0 2.88000
39 RHODE ISLAND	113200.0 0.08640	519900.0 0.80900	38760.0 0.33600	93730.0 0.35400	29390.0 0.16100
40 S CAROLINA	1209000.0 0.92300	1076000.0 1.67000	146300.0 1.27000	260500.0 0.98500	483900.0 2.65000
41 S DAKOTA	2861000.0 2.18000	69420.0 0.10800	18560.0 0.16100	91110.0 0.34400	23480.0 0.12900
42 TENNESSEE	1789000.0 1.37000	1307000.0 2.03000	264100.0 2.29000	340900.0 1.29000	200300.0 1.10000
43 TEXAS	9302000.0 7.10000	1817000.0 2.83000	695500.0 6.05000	4139000.0 15.60000	1501000.0 8.22000
44 UTAH	2461000.0 1.88000	285400.0 0.44400	48410.0 0.42000	112800.0 0.42600	46840.0 0.25600
45 VERMONT	292100.0 0.22300	112600.0 0.17500	13710.0 0.11900	25460.0 0.09630	14190.0 0.07770
46 VIRGINIA	1607000.0 1.23000	1388000.0 2.16000	197800.0 1.71000	415200.0 1.57000	235100.0 1.29000
47 WASHINGTON	2204000.0 1.68000	626400.0 0.97500	126300.0 1.09000	361800.0 1.37000	425500.0 2.33000
48 W VIRGINIA	1261000.0 0.96200	1455000.0 2.26000	306500.0 2.66000	172800.0 0.65300	435100.0 2.38000
49 WISCONSIN	2180000.0 1.66000	1216000.0 1.89000	231300.0 2.00000	362600.0 1.37000	161300.0 0.88300
50 WYOMING	2851000.0 2.18000	513000.0 0.79800	70570.0 0.61200	275200.0 1.04000	20870.0 0.11400
US TOTALS	131000000.0	64300000.0	11500000.0	26400000.0	18300000.0

TABLE E-1. CONVERSION FACTORS

To Convert From	To	Multiply By
Btu	joule (J)	1.055×10^3
degree Fahrenheit (F)	degree Celsium (C)	$t^o_C = (t^o_F - 32)/1.8$
foot (ft)	meter (m)	3.048×10^{-1}
foot^3 (ft^3)	meter^3 (m^3)	2.832×10^{-2}
inch (in.)	meter (m)	2.540×10^{-2}
mile^2 (mi)	meter^2 (m^2)	2.590×10^6
pound (mass, lb)	kilogram (kg)	4.536×10^{-1}
ton (short)	gigagram (Gg)	9.072×10^{-4}

PREFIXES

Prefix	Symbol	Multiplication Factor	Multiply By
tera	T	10^{12}	$1 \text{ Tg} = 1 \times 10^{12}$ g
giga	G	10^9	$1 \text{ Gg} = 1 \times 10^9$ g
mega	M	10^6	$1 \text{ Mg} = 1 \times 10^6$ g
kilo	k	10^3	$1 \text{ km} = 1 \times 10^3$ g
milli	m	10^{-3}	$1 \text{ mm} = 1 \times 10^{-3}$ m
micro	μ	10^{-6}	$1\ \mu\text{m} = 1 \times 10^{-6}$ m

APPENDIX F

GLOSSARY OF TERMS

ANNEALING - Controlled heating and cooling of glass to remove objectionable stresses.

BATCH - Mixed glass raw materials.

BATCH HOUSE - Structure where raw materials are sorted, weighed, and mixed.

BOOSTING - Supplemental electrical heating in the glass furnace.

CHECKERS, CHECKERWORK - A network of refractory ducts on both sides of a glass furnace, used as heat exchangers.

CULLET - Scrap glass that is to be recycled.

FINING - Process of removing gas bubbles from molten glass.

LEHR - A long oven for annealing glass continuously.

MELT - The molten glass in the glass furnace.

REFINING - Process of conditioning the molten glass to remove gas bubbles and undissolved grains of sand.

TANK - That part of the glass melting furnace which holds the molten glass, made of refractory material.

REGENERATORS - Chambers of refractory checkerwork on both sides of the melting furnace. Hot exhaust gases from the furnace pass through one regenerator and heat it while combustion air passes through the other regenerator and is heated. At intervals of 15-20 minutes, the flow is reversed.

APPENDIX G

LETTERS OF COMMENT

This appendix contains letters from the Glass Packaging Institute (GPI) (formerly GCMI), EPA, and Battelle that address certain points raised by GPI during a review of the Preliminary Source Assessment Document. Some of the comments and suggestions for revision were utilized. The letters from EPA and Battelle are in response to questions raised by GPI, and were included at the request of GPI and EPA.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
RESEARCH TRIANGLE PARK
NORTH CAROLINA 27711

May 28, 1976

Dr. John Turk
Glass Container Manufacturers Institute
1800 K Street, N.W.
Washington, D.C. 20060

Dear John:

I appreciate the opportunity for Dr. Schorr and myself to get together with the Air Quality Task Force of GCMI to discuss your comments on the PSAD for the glass container industry. At that meeting, several questions were left unresolved, and I indicated that I would attempt to provide answers for or obtain further clarifications as to EPA position regarding certain policy issues. These issues or questions are outlined below along with my response.

1) Question: What is the national primary ambient air quality standard for nitrogen oxides? What reference method is used for ambient sampling for nitrogen oxide and what species is measured? What is the national primary ambient air quality standard for sulfur oxides?

Answer: The national primary ambient air quality standard for nitrogen oxides is nitrogen dioxide (NO_2). The standard for NO_2 is 100 micrograms/cubic meter-annual arithmetic mean. The proposed reference method for measuring NO_2 in ambient conditions is chemiluminesce. This method, however, has not been promulgated, but is expected to be so in about 2 months. This method indirectly measures NO_2 by first measuring NO in the sample and then reducing the NO_2 to NO in a reducing chamber and remeasuring the total NO concentration in the sample. The difference in the two measurements represents the NO_2 concentration.

The national primary ambient air quality standard for sulfur oxides is sulfur oxides (SO_x) measured as sulfur dioxide (SO_2). The standard for SO_x measured as SO_2 is 365 micrograms per cubic meter-maximum 24 hours concentration.

Conforming with these ambient air quality for these pollutants, the PSAD will referenced these standards as NO_2 and SO_x.

2) Question: If the ambient air quality standard for nitrogen oxide is for NO_2, how is EPA justified in comparing an NO_x emission which is predominately NO species emitted from a glass melting furnace to NO_2 ambient air quality standard.

Answer: I have discussed this issue of comparing a predominately NO emission species against a NO_2 standard with our physics and chemistry experts at RTP. In making this comparison, this assumes that the NO_2 emission factor is equal to the NO_x emission factor. They feel (and I concur) that this assumption is a fairly good one for the following reason. Once the plume has been diluted sufficiently with air (dispersion calculations show that the plume is diluted approximately 1000 to 1 at the point where it touches ground), the photochemical conversion of NO to NO_2 is quite rapid particularly in a urban environment. Studies has shown that the NO half life due to conversion to NO_2 is approximately one hour. In a rural environment, it is approximately an order of magnitude higher. Based on this evidence, our assumption of using an NO_x emission factor to represent NO_2 emission factor appears to be good. Unless the task force has ambient air sampling data to the contrary, we feel justified in comparing the NO_x emission factor to the NO_2 standard.

Secondly, if we were to use NO as the reference instead of NO_2 for our source severity calculation, the risk factor (TLV X $\frac{8}{24}$ X $\frac{1}{100}$)

would be the same as the ambient air quality standard for NO_2. The TLV for NO is 30 mg/m^3 and when adjusted using our safety factor of $\frac{1}{300}$ $(\frac{8}{24} \times \frac{1}{100})$, the risk factor becomes 100 $\mu g/m^3$ for the source severity calculation which is the same as ambient air quality standard for NO_2. Therefore, in either case, the source severity calculation would remain the same.

3) Question: The safety factor of $\frac{1}{100}$ appears to be conservative in the risk factor based on a comparison between TLV's and ambient air quality standards for criteria pollutants.

Answer: I have reviewed the data comparing our risk factor for source severity based on TLV's and then on an Ambient Air Quality Standard for criteria pollutants. It would appear that we have one to one correspondance between the two basis for determining exposure which would cause an adverse health effect if for SO_x and particulates, a safety factor of 10 is used; for NO_2, a safety factor of 33 is used; and for CO, a safety factor of 1000 is used. I have discussed this issue with several people at RTP. Our conclusion is to leave the safety factor at 100. The reasoning is as follows: Expert judgement recommends a safety factor of 100 to account for exposure to a general population instead of a healtier working population. Also, there is no reason to believe that all other pollutants will have the same safety factor as evidenced by CO being off by a factor of 1000. Additionally, the health effects are better known and studied for the criteria pollutants for which ambient air quality standards have been set, than for those pollutants for which no standards have been set to date. For these reasons, we will continue to use the safety factor of 100 in our source severity calculations for non criteria pollutants.

If my responses to these questions or issues are not satisfactory to the Task Force, I will be glad to discuss these issues with them in person at their convenience. However, I do hope they shed some light as to our current thinking on these issues. Again, let me thank you and the Task Force for your help in reviewing this document.

Sincerely,

E. J. Wooldridge

E. J. Wooldridge
Chemical Processes Branch

cc:
Dr. Dale A. Denny
Dr. J. R. Schorr

Glass Container Manufacturers Institute, Inc.

gcmi

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July 2, 1976

Mr. Ed Wooldridge
Reasearch Triangle Park
Environmental Protection Agency
Research Triangle Park, NC 27711

Dear Mr. Wooldridge:

Enclosed herein are limited comments from the GCMI Air Quality Task Group relative to your June 1976 Draft Source Assessment Document. In view of the time limitation imposed by your current schedule for finalizing this report, we have had to hastily distribute copies of the draft, and have been unable to give it enough attention for a comprehensive review. A full word by word analysis of this report has not been attempted. However, several questions have been raised where treatment was questionable, and the apparent impact of a glass manufacturing operation was seriously in error. I would like to point out that this draft still contains several errors, significant internal contradictions, incomplete editing, and also shows a lack of attention to errors pointed out in earlier drafts for which there were agreed changes to be included.

The incorporation of the attached suggestions will still not mean that we are in accord with all of the remaining content of the report for the reasons given above.

The Air Task Group is very much concerned at the rush to issue this report in view of its current state, and the lack of time for comment allotted to the GCMI Task Group, which has attempted the fullest cooperation possible in the preparation of this document. We wish to call to your attention to earlier communication between Battelle, EPA, and GCMI concerning the time available for proper preparation of this source assessment. At our first meeting, September 30, 1975, in Washington, you clearly stated that there were no time constraints in publishing on this report. It was with this understanding that there would be adequate time for constructive comment and corrective action that the Committee agreed to cooperate in the source assessment study. We regret that we consider further time necessary to complete this document so that appropriate data is included and objective analysis is performed, as this process is time consuming and expensive to our membership, as well as to Battelle and EPA. We sincerely request that the following comments be considered objectively and that appropriate revisions to the source draft be made and reviewed before any consideration of a printing of the final document is considered.

Nitrogen Oxides from Glass Melting Furnaces

In earlier meetings, we have questioned several aspects of the treatment of nitrogen oxides from glass melting in determining ambient impact of the plant. First we questioned representation of total nitrogen oxides as the regulated pollutant. It was clarified that nitrogen dioxide is the regulated pollutant. Then we were informed that in converting a threshold limit value for nitric oxide to a simulated ambient standard the value for nitrogen oxide would come out equivalent for nitrogen dioxide. (This relation depending on the use of 1/100 "safety factor"). We had earlier commented on the questionable use of the safety factor, and it is appropriate to further point out that were this a recognized approach for setting a standard there would have been no justification not to regulate total nitrogen oxides, rather than consider nitrogen dioxide the pollutant.

We also questioned treatment of the furnace emissions as nitrogen dioxide, since in nitrogen oxide emissions for combustion processes, glass melting not exclusive, it is well established that approximately 95% of the total oxides are emitted as nitric oxide (NO). We seriously questioned this treatment in determination of a maximum ground level concentration only a few minutes residence time from the point of discharge. The EPA response indicated the treatment is based on "rapid" conversion of nitric oxide to nitrogen dioxide in the atmosphere, with the half life on one hour cited. Our own reference searches have not turned up a good documentation of atmospheric residence, rather referring to a range of anywhere from a few hours to a few days. However, we consider our question still valid, for reasons which will be shown later.

Referring to Table 12 of the June draft, we note the "representative" plant contains a single glass melting furnace discharging through a single stack. We note the glass tonnage of this furnace has been increased from 80,000 tons per year in the preceeding draft, to 115,000 tons per year in the current draft. Using a typical production schedule of 350 operating days per year, 115,000 tons per year equates to 329 tons of glass per day, a very high tonnage for a "representative" furnace. Since the nitrogen oxide emission rate is directly correlated to production tonnage, this illustration would be more representative of near the maximum level of nitrogen oxide emissions, not a "representative" level.

We note in the same section of Table 12 gas flow rate and temperature are shown. These are unchanged from the earlier draft. Considering a conservative 5.5 million BTU's per ton to melt glass, and a typical 8% stack oxygen level, we can only account for the production of about 250 tons of glass per day at this exhaust flow. This, together with a nitrogen oxide emission rate based on the higher tonnage, produces an imbalance which shows nitrogen oxide emission concentrations (which will be directly reflected in downwind level concentrations) about 32% too high. (Supporting calculations are attached to this letter).

From Table 16, we find the maximum downwind concentration is located a distance of 880 meters (2,887 feet) from the stack. From Table 12, we pick the average wind speed used in the dispersion calculation of 6 meters per second (19.8 feet per second). Relating these two, we can determine the residence time of the nitrogen oxide from the point of stack discharge to the point of maximum downwind concentration is 2.43 minutes.

Using the one hour half life for the oxidation of nitric oxide, as provided by Mr. Wooldridge, we can calculate that in the 2.43 minutes atmospheric residence time of the nitrogen oxides only 3% of the emitted nitric oxide will have time to convert to nitrogen dioxide. Assuming that we start with the well established 95% nitric oxide: 5% nitrogen dioxide ratio, at the end of 2.43 minutes in the atmosphere we calculate that a total of 7.85% of the nitrogen oxide is nitrogen dioxide at the point of maximum downwind concentration.

If we concede (ignoring the 32% high value for nitrogen oxides) 11.25 grams per second emmitted, only 1.35 grams per second of this can legitimately be treated as nitrogen dioxide for the purpose of determining ambient dispersed concentration at the maximum downwind concentration location. If this correction is not made, we calculate that the nitrogen oxide value represented is 833% of the correct value.

In referring to Table 14, we first note the regulated pollutant is again represented as total oxides of nitrogen. The pollutant, of course, should be nitrogen dioxide. We next note the represented quality standard is the annual arithmetic mean of 100 micrograms per cubic meter, which, for the purpose of this exercise is assumed here as a 24 hour standard. We do not believe this is a legitimate assumption. In fact, we believe it introduces further error in the analysis. We also believe other authors have related an annual mean to a 24 hour standard by a ratio of about .3. Indeed, in reviewing the ratios between annual and 24 hour for particulates (primary and secondary) and for sulfur dioxide, pollutants where both annual and 24 hour standards exist, we find the Federal EPA related them as ratios of .29, .40, and .22, respectively. We submit that it would be consistant with EPA practice for a ratio of .3 to be used in converting from a one year to a 24 hour standard. With reference to Table 14, an appropriate 24 hour standard for nitrogen dioxide would, then, be 333 micrograms per cubic meter. Calculating in the other direction, converting a 3 minute maximum to an annual mean, one would insert the multiple of (.36) x (.3), or .11, as the scaling factor. We take note that Turner, who provided the basis for the scaling factor from the three minute sample to a 24 hour sample, had questioned using his own data for scaling for sampling times of greater than two hours. This points out that even experts in the field of ambient dispersion, consider these statistical treatments uncertain, and certainly, in our view, adds question to the practice of weighting every calculation to the most severe disadvantage of the source.

To summarize the corrections we feel are legitimate, we have prepared a new Table 14 for your study.

If we use the new figures that we calculate for maximum downwind concentration of nitrogen dioxide, we would expect to see an increase in background nitrogen dioxide concentration of only 4.55 micrograms per cubic meter, which we doubt is measurable with current analytical accuracy. To further illustrate the low ambient nitrogen dioxide impact within the vicinity of the plant, we are attaching a report summarizing ambient sampling of a members operating factory. This was done under the indirect supervision of the San Joaquin County Air Pollution Control District of California and EPA Region 9, and has been given to Region 9 in its entirety. The ambient samplers were located where results from EPA's UNAMAP computer program indicated a maximum ground level concentrations would be found. Refer to Table 7, Figures 1 and Figures 6-9, for the nitrogen dioxide analyses. As is apparent in the data, the plant contribution to the nitrogen dioxide background is not evident. It should be specifically noted, that the measured total nitrogen dioxide background is not as high as the predicted contribution from the furnace alone as represented in the Battelle report.

Hydrocarbons from Forming and Finishing - (Principally Decorating)

Table 2 shows an emission factor of hydrocarbons from forming and finishing as .36 grams per kilogram of glass produced (.72 pounds per ton). Based on an annual decorated tonnage of 364,000 tons (3% of total annual production) the industry emits from the forming - finishing operation a calculated 131 tons per year of hydrocarbons. While we believe the factor of .36 gms/Kg is high, our real question of the treatment of hydrocarbons relates to the assumptions used for the dispersion calculations.

From Table 15, Source 2, we see the single source used in the calculation emits 79 tons of hydrocarbons per year, or an astonishing 60.3% of the total annual emission for the industry.

Calculating another way with the Table 2 and Table 15 data, we can calculate this sample source has to decorate 219,000 tons of glass a year, or 190% of the glass produced in this sample plant (reference Table 12). Either of these calculations illustrates that the emission assumptions used for dispersion calculations are absurdly high.

Even assuming the hydrocarbon factor from Table 2 to be correct, and further assuming the rest of the calculation is right, choosing the realistic decorated tonnage we have given above and recalculating, would show a greatly reduced severity factor.

Summary Comment

A strong motivation of the glass industry in cooperating in the development of this source assessment study has been to see that a fair and impartial treatment is given the glass container industry and its impact on the surrounding area and effected population. We are certainly not attempting to obscure or cloud facts or potential problem areas.

While we would appreciate your incorporating the above comments into the final report, we still would not be in a position to indicate to concurrence with the balance of it since we have not had ample time to review it in detail.

As noted previously, our comments simply point out some of the more obvious errors. We note that this report still contains many errors and significant internal contradiction.

Sincerely,

John G. Turk
Vice President - Technical

JGT/bb

Attachment(s)
✓cc: Dr. Richard Schorr

Battelle
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Telephone (614) 424-6424
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August 20, 1976

Dr. John G. Turk
Vice President - Technical
Glass Containers Manufacturers Institute
1800 K Street, N.W.
Washington, D.C. 20006

Dear Dr. Turk:

In reply to your letter of July 2, 1976, regarding changes in the draft final of the source assessment document (SAD) on glass containers, we have reviewed these comments along with representatives from EPA and would like to offer the following consensus opinions.

Your letter refers to several serious errors, significant internal contradictions, and several other faults, but we can only deal with the ones which were actually called out; and this has been done.

Nitrogen Oxides

We do recognize your position regarding nitrogen oxide emissions but fail to find any reasonable basis on which to change the report. Nitric oxide is not the only oxide of nitrogen leaving the plant site, and little evidence is available to document its relative proportion. However, the report does point out the NO is the predominant specie. The report from Owens-Illinois was most informative but does not really seem to conflict with the general conclusions of the SAD. It is well demonstrated that NO_x emissions can vary widely depending upon the operating conditions of the melting furnace. Mr. Wooldridge's letter of May 28, 1976, we believe clearly indicated that the calculations for source severity were not changed by assuming NO to be the pollutant instead of NO_2, because of the safety factor used for non-criteria pollutants. Again, it is important to remember that the purpose of these studies is not to set standards but rather to define the needs for control technology development in the glass industry.

Regarding other specific comments in your letter, Table 12 represents the emissions from the entire plant's melting furnaces and not a single furnace. The title will be changed to more clearly reflect this. The treatment of the data in Table 14 has been checked and while we agree that there are a variety of opinions regarding the calculation of maximum pollutant concentrations and source severity, the treatment which we used is generally consistent with that done in source assessment documents for other industries.

Hydrocarbons

The hydrocarbon emissions in Table 15 came from NEDS. We are currently reevaluating why this number was so high. We believe the number to be in error and that we perpetuated the error. Dropping this number would lower the emission rate in Table 15 to 2.88×10^{-2} gm/sec (1 ton/year) and change the values for X_{MAX} (3 minutes) and X_{MAX} (3 hours) to 3.11 and 1.58 $\mu m/m^3$, respectively, and the severity factor to 9.9×10^{-3}.

Summary

I would like to note that very little actual emission measurement data was supplied to Battelle by GCMI for use in the conduct of this study. This is contrary to what is implied by your letter of July 2, 1976.

We are most concerned that the report be consistent with other studies of like nature and that it accurately reflect the data available to us. Your letter contains many statements inferring just the opposite.

Should you have any additional questions regarding the report, you may call me on Extension 3624. After making final changes, the report will be duplicated and copies sent to you, as per Ed Wooldridge's requests.

Very truly yours,

Richard Schorr

J. Richard Schorr, Manager
Ceramic Materials Section

JRS:ak

cc: Mr. Ed Wooldridge

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October 18, 1976

Dr. Dale Denny
Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Dear Dr. Denny:

We appreciate the opportunity extended the Glass Packaging Institute (formerly Glass Container Manufacturers Institute) Air Quality Task Group to attach comment to your final report "Source Assessment of the Glass Container Manufacturing Industry", Contract Number 68-02-1323, Task 37.

As we understand from our phone conversation on or around September 17, 1976 with you, your procedure does not allow us time to see and comment on the final draft document before it is made public. Our comment, therefore, is not a critique of the wording and data of the final draft, as obviously we have no confirmation of what is to be in that draft.

Rather than submit further detailed comment, as we have done in reviewing the two earlier drafts of the Source Assessment report, we wish to relate to you some general observations we have about the Source Assessment project, the format of this project, and the handling of data. Specifically, we wish to comment on four general points to which we attach considerable significance.

1. General Report Format and Project Perspective

The major concern we have with the format of this study, as it was presented in the earlier report drafts, is that the summary presentation does not allow us, or others, to develop a perspective about the significance, or severity, of the emissions. Although we understand it is not the responsibility of the contractor to draw conclusions, we do believe the summary format could include the criteria to be used by EPA in evaluating the sources, and in defining the need for further programs.

2. Significance of Emission Data

The Glass Container Manufacturers, through the Glass Packaging Institute, have attempted to provide assistance in collecting emission data for this study. Information has been provided through response to requests from the contractor for emission data, or by way of comment concerning the draft reports. Referring to the draft of June, 1976, the industry is satisfied that a fair representation of the process emissions is reported. We question comments by the authors, inferring inadequate data still exists.

Comparing the emission summary of Table 2 with comments in the text, we note some contradictions. The emission summaries of Table 2 are reported in a manner indicative that statistically significant data has been collected. However, for some minor process sources, the authors have indicated relatively few individual measurements were available to them. We question performing a large number of expensive measurements on sources which initial data and process analysis indicate to have negligible emissions and insignificant ambient impact. We believe for those processes which have a detectable ambient concentration, there is represented in the report an adequate body of data from which to draw conclusions.

3. Calculation of Ambient Concentration in Source Severity Determination

The format provided the contractor for determining source severity is the calculation of maximum downwind ambient concentration (by common equations after Turner) and direct comparison with ambient air quality standards or converted threshold limit values. Where the emitted specie is chemically the same as the "regulated" compound, the resultant source severity comparison can be reasonably represented as a worst case example. However, where the emitted compound is not a regulated compound, but is a precursor (that is, by atmospheric conversion or reaction may become the regulated compound), the question of reaction time and reaction rate cannot be ignored in the projection of the maximum ambient concentration of the regulated pollutant.

In the glass container source assessment, the treatment of nitric oxide (NO), where it is assumed to react immediately to form nitrogen dioxide (NO_2) is questionable. The reaction of nitric oxide to form nitrogen dioxide is not instantaneous, but is more on the order of hours to days, depending on atmospheric conditions. The point of maximum downlevel concentration of the effluent from a glass furnace is, timewise, only two to three minutes. Only a small portion of the nitric oxide can be converted in this time interval, (3 to 5%). The simplification then, in assuming instantaneous reaction in this case, predicts the source impact approximately ten times higher than it should. (Additional comments about the mathematics of ambient disbursion calculations, and the conversion units used in the Glass Industry Source Assessment are attached to this letter.)

The treatment of nitric oxide emitted is of concern to us in the glass industry. However, we wish to point out a generalized treatment of this form will be a problem to any industry, so evaluated, which emits a material considered precursor to any pollutant when instantaneous reaction to form that pollutant is assumed rather than a reaction time representative of the known reaction rate and chemistry.

4. Treatment of Control Technology

A stated purpose of this project was to determine where pollution control technology or process modification is needed. Another purpose of this report was to determine where control or process technology is currently unavailable or unsuitable. It is our opinion that any useful discussion of emission reduction technology must consider technical feasibility and economic practicality considerations.

The treatment in the two draft reports has considered neither technical nor economic factors but, instead, has been simply a listing of claims and promotions from various sources, with no screening of fact. We believe such a treatment has no value in enlightening one as to what technology is available, adequate or economical, or what development needs exist.

Sincerely,

John G. Turk
Vice President - Technical

JGT:drh

cc: E. Wooldridge - EPA
R. Schorr - Battelle

APPENDIX

Ambient Source Severity Determination of Pollutant Precursor

The preponderant nitrogen oxide formed in a combustion process, such as in a container glass melting furnace, is nitric oxide (NO). Measurements on operating furnaces and literature references indicate no more than 5% of the total oxides of nitrogen is nitrogen dioxide (NO_2), the regulated pollutant.

Nitric oxide is considered a precursor to nitrogen dioxide in atmospheric reaction. References to the rate of atmospheric conversion of nitric oxide to nitrogen dioxide are not specific. Rather, they refer to a range of a few hours to a few days, depending on atmospheric conditions. EPA project personnel, responding to our original comments about atmospheric reaction, indicated the conversion to be "rapid," and cited a half-life for the reaction of one hour. A half-life of one hour is used in calculations presented in this correspondence.

Furnace ambient dispersion calculations by the contractor (June, 1976, draft report) located the point of maximum downwind concentration of emissions a distance of 880 meters (2,887 ft) from the furnace stack (Table 16). The average ground wind speed used in the dispersion calculation was 6 meters (19.8 ft) per second (Table 12). Using these values, the calculated residence time from the point of stack egress to the point of maximum downwind concentration would be 2.43 minutes.

Using the one hour half-life for the oxidation of nitric oxide, only 3% of the emitted nitric oxide will be converted to nitrogen dioxide in the 2.43 minute atmospheric residence time. Assuming an emission of 95% nitric oxide: 5% nitrogen dioxide, only 7.85% of the total nitrogen oxides would exist as nitrogen dioxide at the point of maximum downwind concentration.

The ambient air quality standard for nitrogen dioxide is 100 micrograms per cubic meter, annual arithmetic mean. The mathematical ambient dispersion calculation used represents a 3 minute maximum sample. The question, then, is conversion from a 3 minute maximum to an annual mean. A common scaling factor for converting from a 3 minute to a 24 hour maximum is the multiple, 0.36.

The comparison of a 24 hour maximum and an annual arithmetic mean is a point of disagreement. The format of the June, 1976, draft was to assume the 24 hour and annual values to be the same. We disagree. Most authors relate an annual arithmetic mean to a 24 hour standard by a ratio of about 0.3. In reviewing the ratios between annual and 24 hour standards for particulates (primary and secondary) and for sulfur dioxide pollutants, we find the Federal EPA related them as ratios of 0.29, 0.40 and 0.22, respectively. This is in good agreement with a general ratio of 0.3 for the conversion. In converting, then, from the 3 minute maximum to an annual mean, the multiple of (0.36) x (0.3), or 0.11, should be used as the scaling factor.

A further point of disagreement is the $\frac{\sigma z}{\sigma y}$ ratio used in the formula to calculate maximum ground-level concentration (Page 55, June, 1976 draft). For D (neutral) atmospheric stability, the stability class used, the authors cite a value of 1.6 (and appear to use the reciprocal, 0.63, in the calculation). The actual ratio shown in the cited Turner reference is 0.46.

The following restatement of the NO_x portion of Table 14 illustrates the effect of correcting the scaling factor, correcting the $\frac{\sigma z}{\sigma y}$ ratio in the dispersion formula and considering only the portion of NO_x calculated to exist as the pollutant, NO_2, at the point of maximum ground-level concentration.